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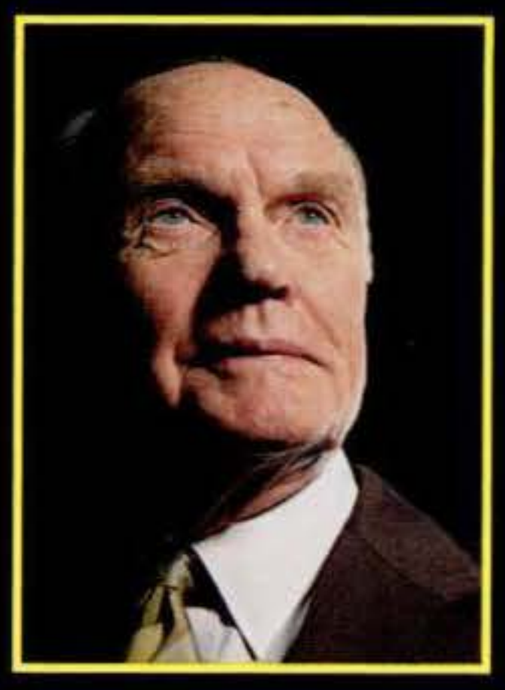

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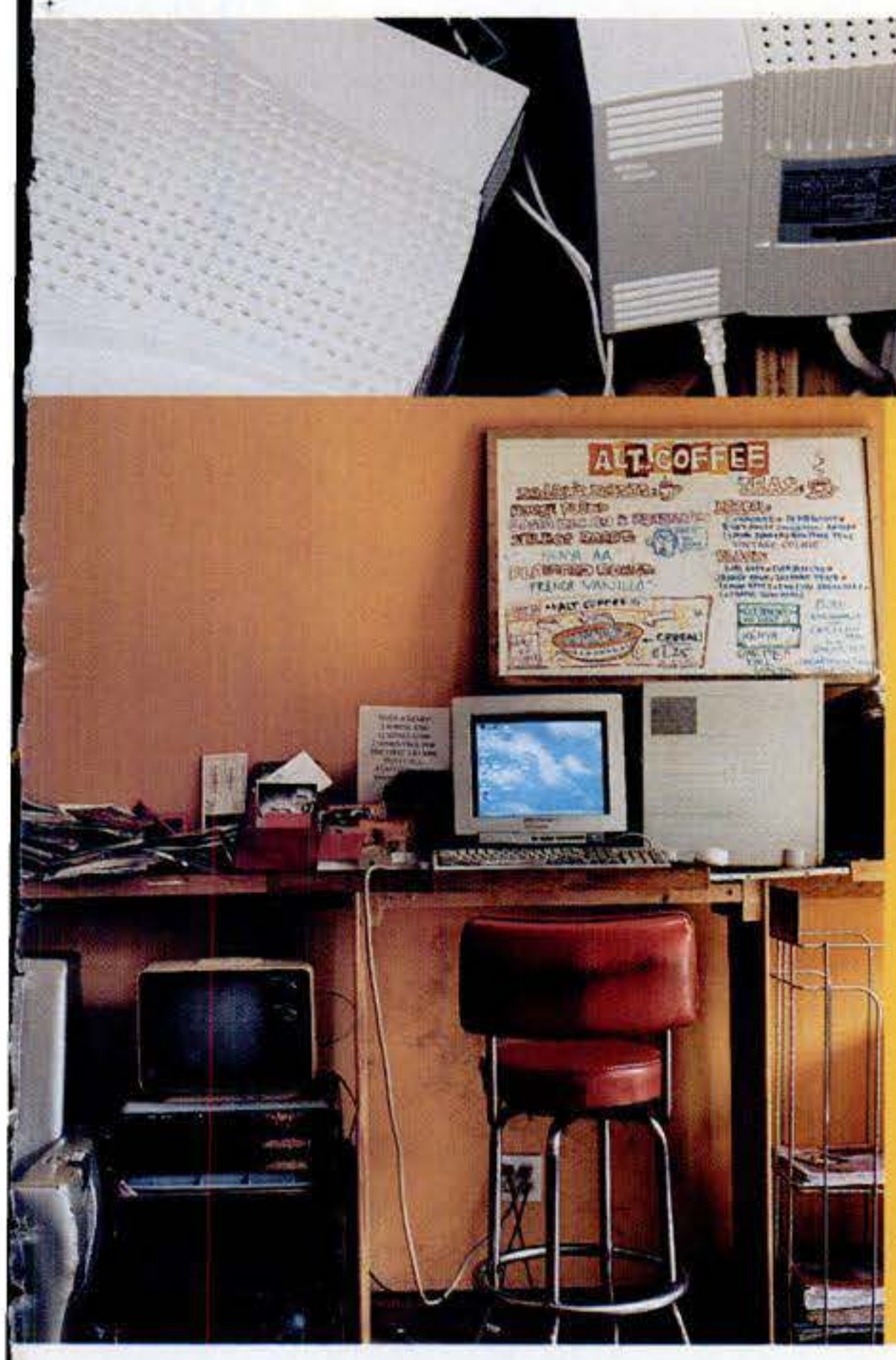

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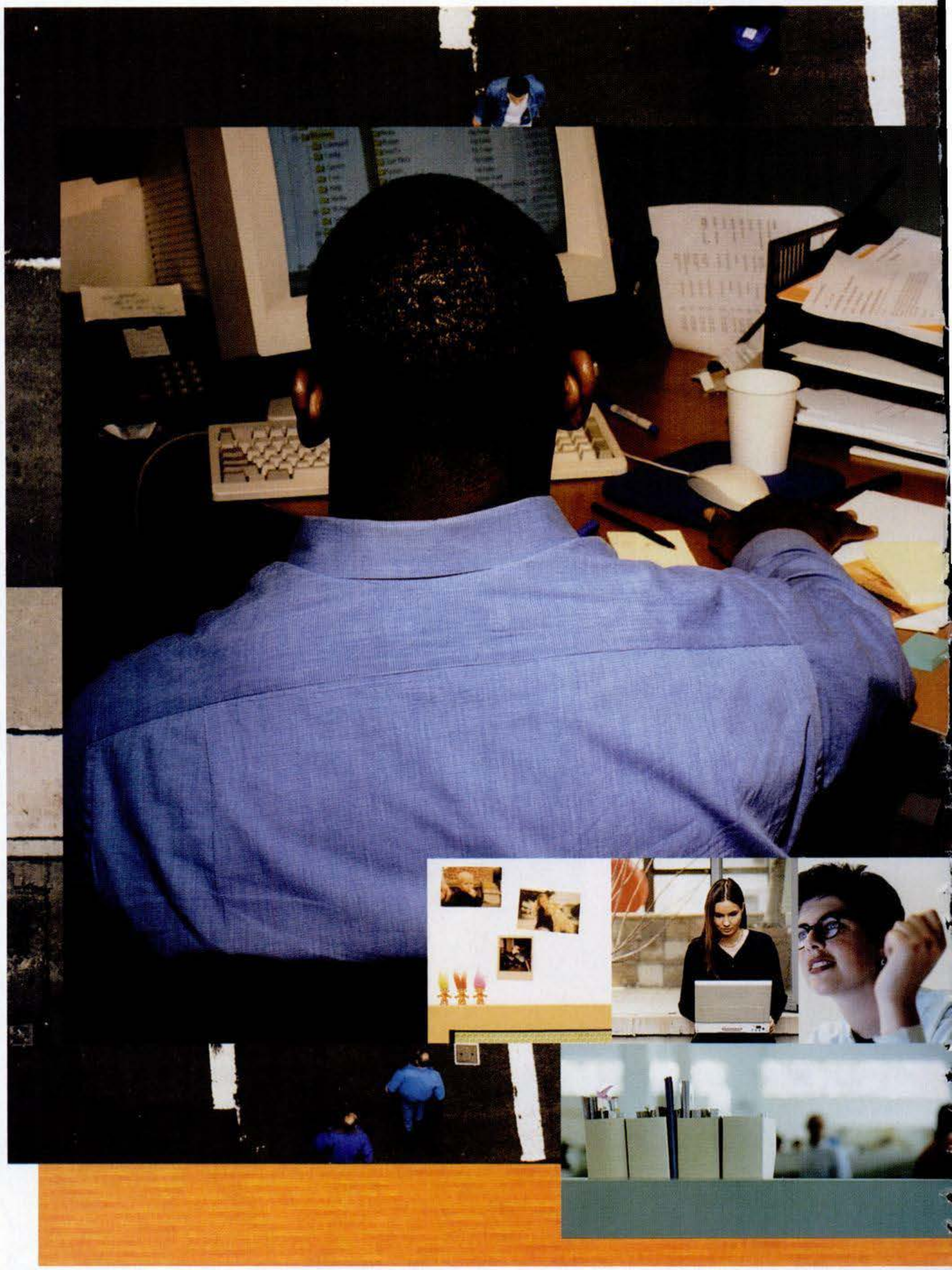

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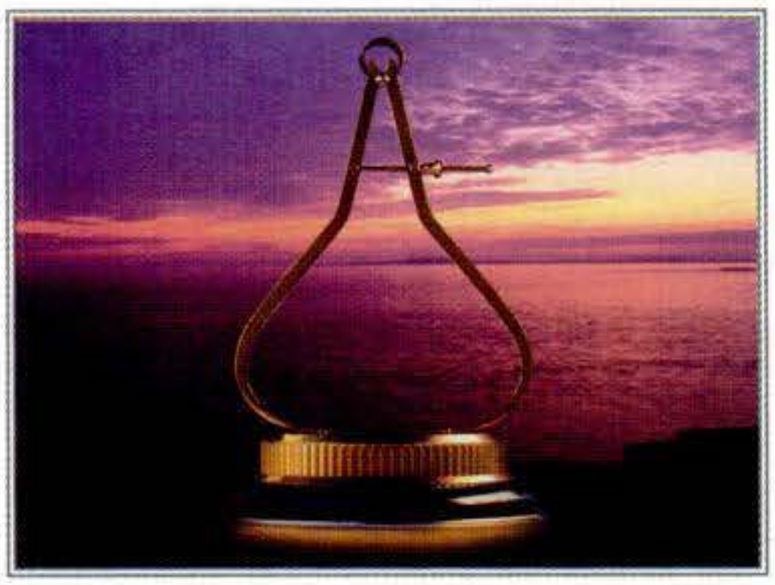
{The honest-to-goodness truth

If we had just removed the roof,

By David Hill, Cor

When we set out to create the C5 Corvette, winning awards was never our intent. That said, it's always nice to be recognized by automotive



{ We're proud to announce that the C5 Corvette is the recipient of the 1998 *Motor Trend* Car of the Year Award. }

cognoscenti. Our aim was to make a sports car that handles superbly, whether a coupe or a convertible. To achieve that end, it was critical that we didn't chop the top off a coupe and call it a convertible. Rather, we had to design the newest Corvette as a convertible right from the outset. It was the best way, the only way in our minds, to make a car with extraordinary feel and handling.

Stiffness and Strength We didn't want this car to suffer from the ride setbacks other convertibles typically have. One particular concern was how to avoid cowl shake, a common side effect of removing a car's roof. So, we made the structure very rigid. The previous 48-piece frame rails were replaced with twin seamless hydroformed tubes. Our new hydroformed frame rail is much more durable than a welded-up one. In fact, the structure was tested to endure up to three life-times of Corvette usage. And not only is the C5

{The C5 was designed without a roof from the beginning so we

four-and-a-half times stiffer structurally than its predecessor, it also has a lower curb weight. The difference in rigidity is immediately noticeable; lateral shake is virtually gone. Ride and handling are coupe-like.

The Next Corve

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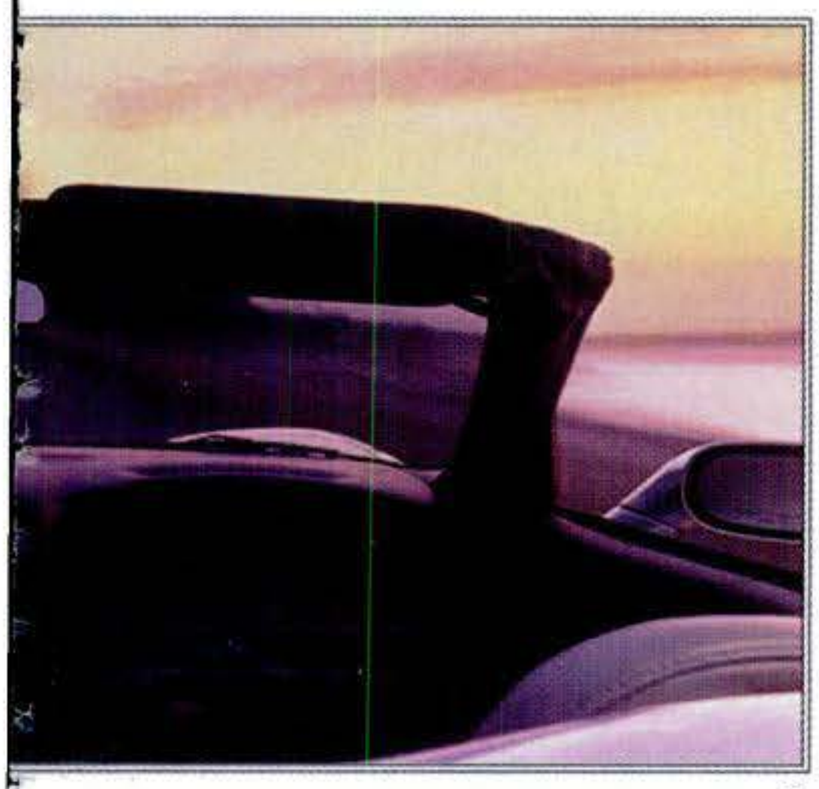
bout the C5 Corvette, after all.}

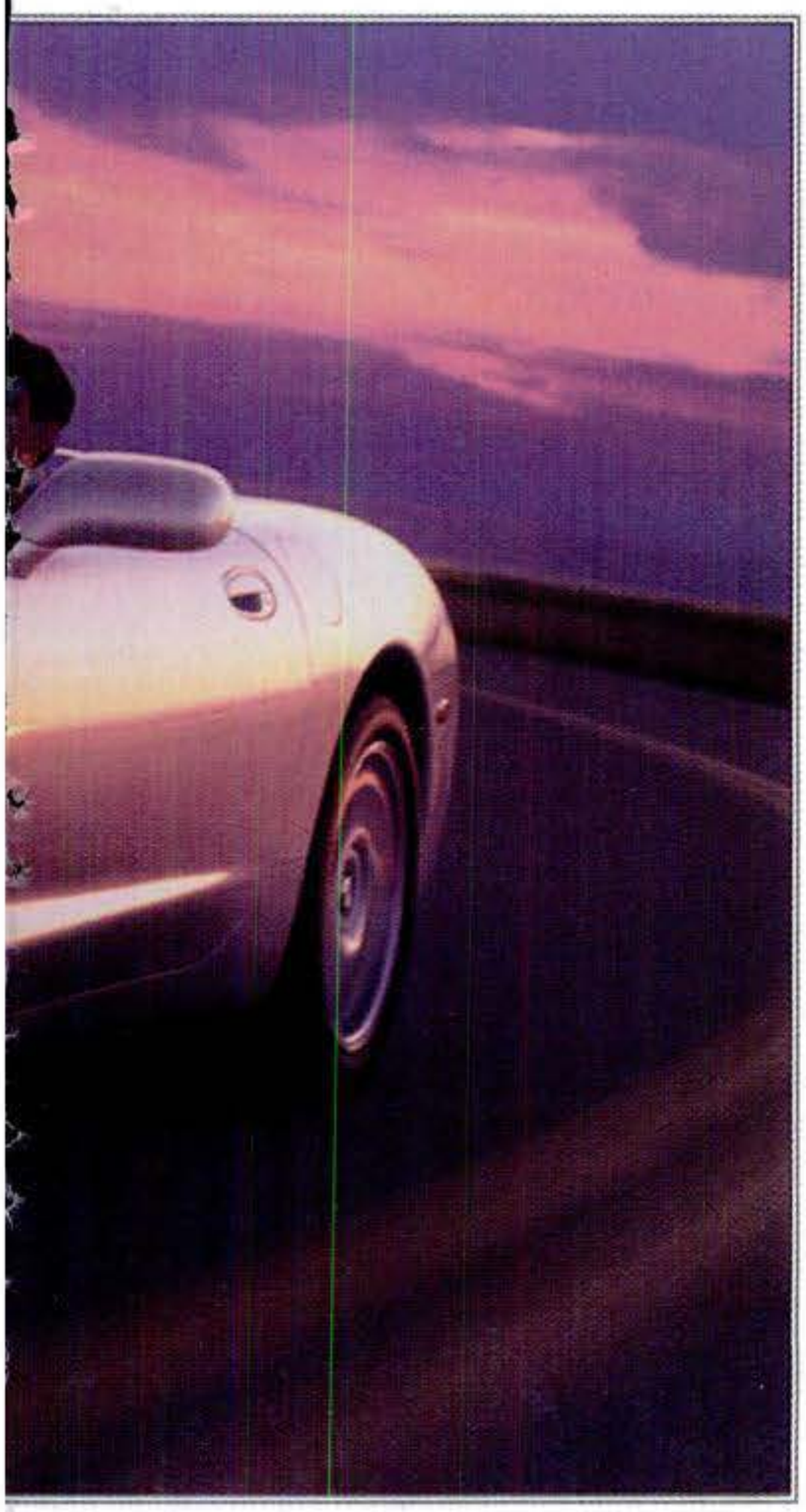
t would have been a tragedy.

te Chief Engineer



uld make a world-class sports car that's also a convertible.}

A User-Friendly Convertible Once we perfected the structure, our next priority was to make every millimeter of the car work for the driver, especially in terms of comfort, spaciousness and cargo. We wanted the car to be easy on the driver, a rare feat in convertibles. So, the controls and functions were placed where it would be natural to reach for them. Entry and exit are easier because doorsills are almost four inches lower. We've increased the hip, shoulder and leg room. There is four times more cargo space with the top down than with a C4. Partly responsible for this are the run-flat tires, which make a bulky and weight-adding spare tire unnecessary. (The instrument panel will alert drivers when a tire needs air.) These measures were taken simply because we wanted customers to avoid inconvenience wherever possible.



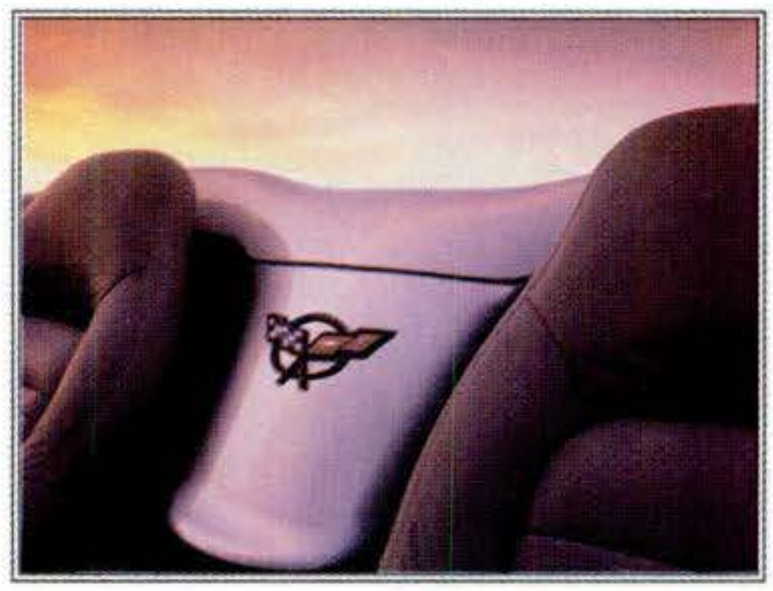
t t e

Power and Performance An obvious worry was whether we would lose the true spirit of a sports car by making it too civilized. We went to great lengths to keep that spirit alive. The newest Corvette has an aluminum small-block V8 that produces 345 horsepower at 5600 rpm, 350 lb.-ft. of torque at 4400 rpm and, in coupe form, achieves a 175-mph top speed.

Although it delivers more horsepower and torque than the iron version it succeeds, the C5 engine weighs 44 pounds less and is smaller in size. Basically, we packed more power into a more compact unit. We could keep the hoodline low, which would improve both aerodynamics and driver visibility.

Making No Compromises Perhaps the most vocal customer opinion was that they wanted a no-compromise sports car; they didn't want to sacrifice ride comfort for the sake of performance. We found breakthrough methods to meet those requirements. Like the composite, balsa wood-cored floor. It minimizes vibrations for the cockpit occupants, while being both lightweight and strong enough to help deliver a more fatigue-free driving experience.

The stiff new structure and revised suspension also demonstrate how there are no take-aways in the new convertible. By shifting the transaxle to the rear, we opened up more leg room. This also freed up room for a structural tunnel down the middle of the car, which increased its rigidity. That rigidity lets the suspension do its job properly; instead of compensating for chassis flex, it can focus on the most important things: precise handling and a smooth ride.



{ Design attributes like the nostalgic waterfall make the new C5 immediately recognizable as a Corvette. }

The Next Corvette The C5 convertible proves it is possible to marry high performance with top-down freedom. Simply put, this thing is incredible. Even more than the coupe, it will far exceed people's expectations. It even exceeded mine. See why on the showroom floor.

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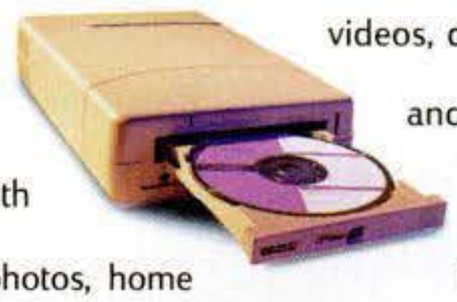

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THE WHAT'S NEW MAGAZINE

Popular Science

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100
Stellar Metropolis
Various visions of space habitation prefigure the ISS.

COVER ART
BOB SAULS/
JOHN FRASSANITO
& ASSOCIATES
Inset: JOHN B. CARNETT

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A Leap of Faith: the International Space Station

IS THE INTERNATIONAL SPACE STATION THE NEXT glorious adventure of discovery and achievement—or the colossal waste of time and money that some critics claim? As with so many seemingly impossible quests, the real measure of the ISS will play out over time. In one of the most ambitious editorial projects POPULAR SCIENCE has ever undertaken, we offer a preview of the ISS: an in-depth look at its origins and its promise. From the science experiments astronauts will conduct to what it's like to live in space, it's all here. We even spent a few days training with the station's first American crew. A pullout poster adds a detailed, fact-filled look at the station makeup.

One thing is certain: Building the ISS is the most ambitious space engineering project ever undertaken. But that in itself is a footnote, not a rationale. Building the ISS is akin to doing the next hard thing. How do you put a value on that? Who can put a limit on our capacity to achieve? The ISS is the most cooperative international peacetime venture since the formation of the United Nations. Only in war have nations come together on a larger scale. For $9 a year per person—less than the average cost of what each of us spends annually on snack food—we have an opportunity to collaborate on a project that can help build a lasting peace for generations.

As Randy Brinkley, the station's program manager, puts it: "I feel confident that we'll derive benefits far beyond anything we can comprehend." This is the real value of the ISS: that which can only be imagined.—*Fred Abatemarco*

COUNTDOWN TO LIFTOFF

WHAT DO POPULAR SCIENCE'S READERS think about the International Space Station? To find out, we asked visitors to our Web site to take a poll. Within two weeks, nearly 2,000 people—93 percent of them men—responded. Here's what they've said about the station so far. If you'd like to take the poll, go to *www.popsci.com*. We'll report final results in an upcoming issue.

1. Were you aware that the International Space Station is being built?
- 84% Yes
- 16% No

2. What is the main purpose of the International Space Station?
- 60% To conduct important scientific research
- 24% To ensure the continued existence of manned space missions
- 7% For ongoing educational purposes
- 5% To promote world peace
- 4% To defend Earth against possible alien invasion

3. NASA says building the space station will cost $9 a year for every person in the country. Is it worth the money?
- 86% Yes, it's worth $9 a year to me
- 7% No, I'd rather spend the money on social problems at home
- 7% No, I'd rather have a tax refund

4. If *you* had the opportunity to visit the space station, would you go?
- 82% Yes, definitely!
- 12% Maybe
- 6% No way you could get me up there

5. What is the most you would be willing to spend for a week aboard the space station?
- 23% Less than $1,000
- 31% $1,000–$4,999
- 20% $5,000–$9,999
- 8% $10,000–$24,999
- 6% $25,000 or more
- 12% The sky's the limit

6. If you were aboard the space station, which food would you miss the most?
- 37% Pizza
- 28% Burger and fries
- 12% Ice cream
- 12% Potato chips and soft drinks
- 11% Broccoli

7. What TV show would you ask your family to tape for you?
- 34% "X-Files"
- 22% "Seinfeld"
- 16% "CNN Morning News"
- 11% "Monday Night Football"
- 11% "ER"
- 6% "Baywatch"

8. Which celebrity would you most like to see aboard the space station?
- 26% John Glenn
- 24% Captain Kirk
- 17% Sigourney Weaver
- 15% Tom Hanks
- 13% Michael Jordan
- 5% Socks or Buddy

9. Select the name you like best for the space station.
- 34% International Space Station
- 30% Freedom
- 22% Alpha
- 10% Boondoggle
- 4% Fred

10. Should astronauts be restricted from having intimate relationships aboard the space station?
- 19% Yes, it could be distracting or dangerous to their mission
- 57% No, what they do on their own time is their business
- 24% Don't care

11. If the Russians are permitted to drink vodka aboard the space station, the Americans should:
- 38% Abstain from alcoholic beverages
- 24% Be allowed to drink beer or wine
- 17% Name a designated driver
- 11% Bring the mixers (soft drinks)
- 10% Be allowed to drink bourbon

12. Select the statement that best describes your views about the station:
- 84% Space is a grand adventure—we'll learn a lot living and working on a station
- 10% I'm not sure, but I'm keeping an open mind
- 4% It's a total waste of time, money, and effort
- 2% It's too dangerous to risk human life in space when unmanned probes can bring back information

13. Will the average citizen be able to visit a space station 20 years from now?
- 42% Yes
- 58% No

14. Do you think the U.S. government will use the space station to conduct secret military experiments?
- 69% Yes
- 31% No

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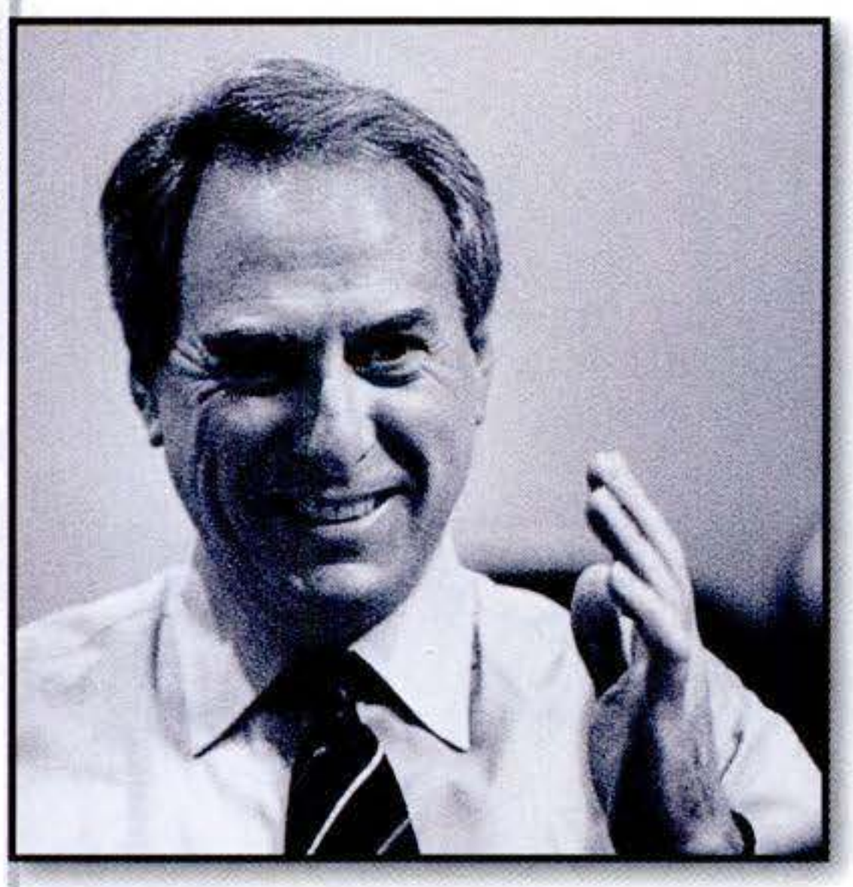
The International Space Station: Striding Toward the Future

BY DANIEL GOLDIN
NASA Administrator

AS NASA MARKS its 40th anniversary, it is taking a bold stride toward the future with the assembly of the International Space Station—the largest peacetime scientific and technological project ever undertaken. It is a tribute and an honor that POPULAR SCIENCE dedicates an issue to this unprecedented endeavor.



JOHN B. CARNETT

It's an endeavor that requires focus and planning. In a fitting example of such characteristics, a young research assistant working at Princeton University in the 1940s recounted how his boss had searched for a paper clip. "We had finished the preparation of a paper and we were looking for a paper clip. After opening a lot of drawers, we finally found one that turned out to be too badly bent for use. So we were looking for a tool to straighten it. Opening a lot more drawers, we came upon a whole box of unused paper clips." His boss, the assistant said, "immediately started to shape one of them into a tool to straighten the bent one. When I asked him what he was doing, he said, 'Once I am set on a goal, it becomes difficult to deflect me.'" His boss's name was Albert Einstein. This focused tenacity and unquenchable thirst for knowledge are shared traits of POPULAR SCIENCE and NASA.

The mission of discovery on which the United States and 15 other nations are embarking will need every bit of those traits. The International Space Station will have more than an acre of solar panels, a pressurized volume equal to two jumbo jets, and four times the electrical power of the Russian space station Mir. And more than 100 pieces will be put together during 45 space flights over the next five years. To say this is a challenge is an understatement.

This world-class laboratory may help members of the international crew bring us new knowledge to unravel physical, chemical, and biological mysteries. Or, without the masking influence of Earth's pull, they may conceive technological advances that will strengthen our economies. Perhaps their long-duration stay aboard the International Space Station will lead to amazing medical breakthroughs that—one day—may save lives.

The orbiting laboratory serves as a symbol of our future. A future that embodies the dreams of our children and that promises untold discoveries for the next millennium. One that fulfills our innate human nature to explore. And one that benefits all people of all nations.

Just like Albert Einstein and his paper clip, NASA will use the International Space Station as a tool in an unwavering pursuit of knowledge. And, of course, as it has done for the past 126 years, POPULAR SCIENCE will be there to write the next chapters in our collective human journey of discovery.

Daniel Goldin, the ninth administrator of NASA, has been head of the space agency since 1992.

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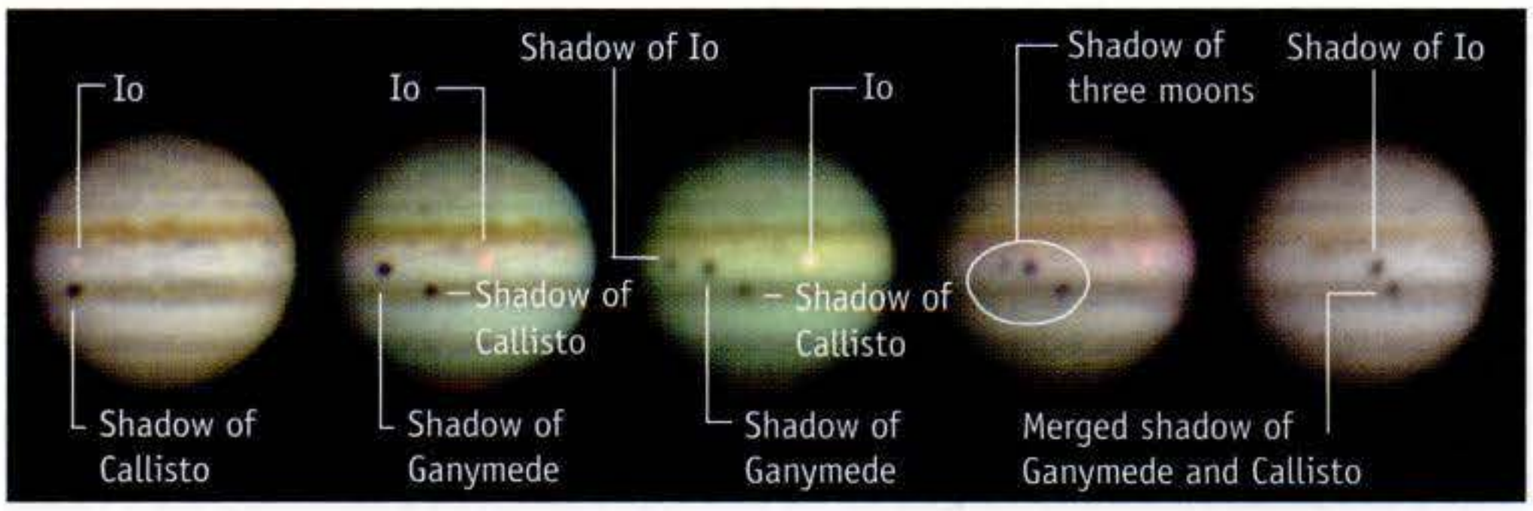

Triple Eclipse

WHEN ONE OF Jupiter's 16 moons passes between the giant planet and the sun, it casts a shadow on the planet's surface. Because Jupiter has so many moons, their shadows sometimes cross paths. That's what happened on November 10, 1997, when astronomers using a telescope at New Mexico State University observed a merging of the shadows cast by three Jovian moons—Callisto, Io, and Ganymede. Such a triple solar eclipse, say scientists, happens only once or twice a century on Jupiter.

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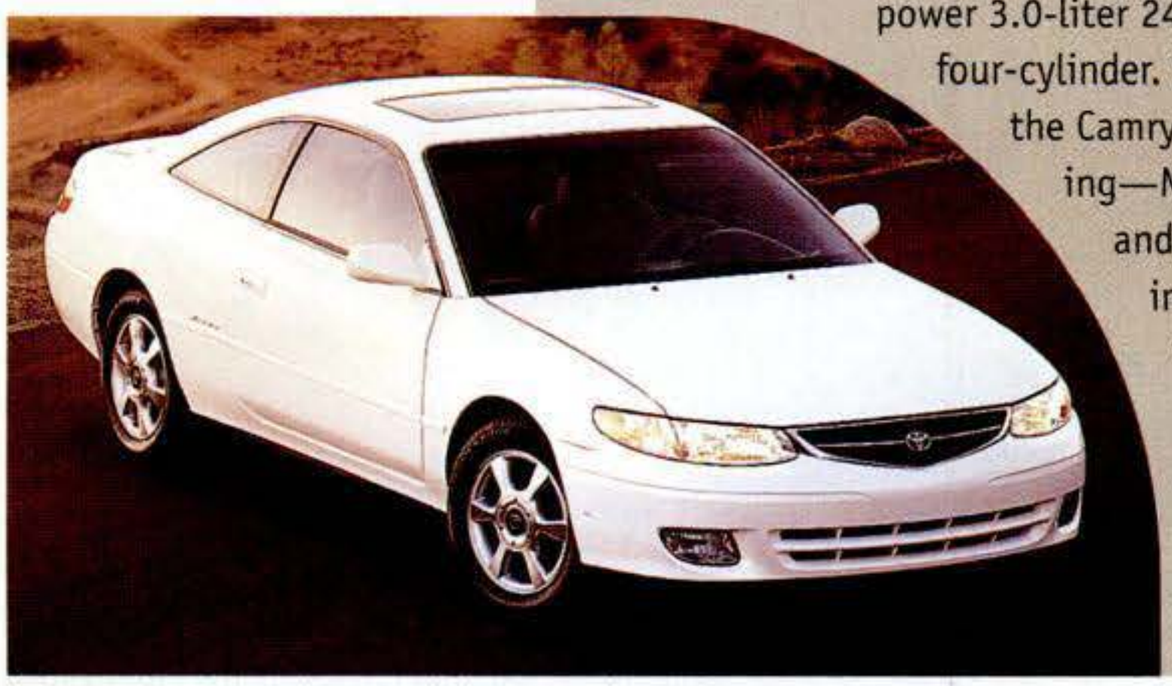
Sporty and Roomy

TOYOTA'S NEW SOLARA is a sporty midsize coupe based on the current Camry chassis. Engine choices are a 200-horsepower 3.0-liter 24-valve V6, or a 136-hp four-cylinder. Suspension is similar to the Camry's, but with firmer tuning—MacPherson strut in front and independent suspension in the rear. The Solara will come with antilock brakes and leather seats standard. The price has not been announced.



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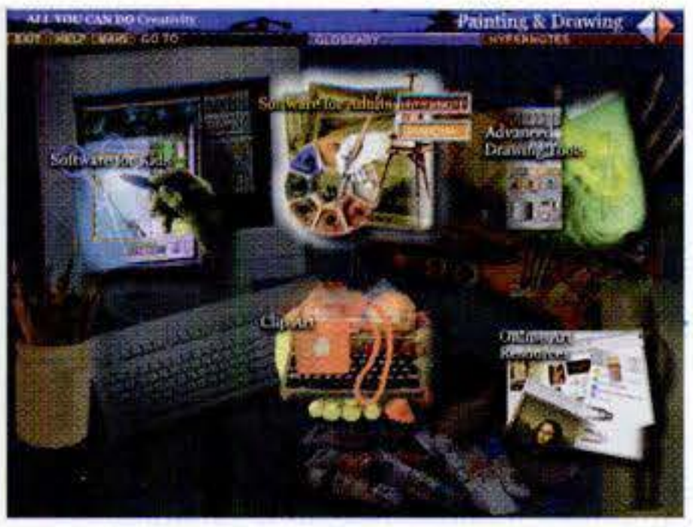

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STAPLERS ARE often held vertically. That's why Hunt Manufacturing created the Boston StandUp stapler. The Deluxe model (shown) features a built-in staple remover. Price: $15 to $25. Hunt Manufacturing, One Commerce Sq., 2005 Market St., Philadelphia PA 19103.

Drop Till You Stop

STANDING 300 feet with a 240-foot drop, the Power Tower is the tallest drop ride in the world by 30 feet. Opening this month at Cedar Point in Sandusky, Ohio, the Power Tower uses 300 pounds of compressed air to shoot riders straight up, imposing gravitational forces equivalent to those experienced on a space shuttle launch. Seconds later, riders plummet to earth at speeds greater than 50 mph. *www.cedarpoint.com*

Voice-Command Headgear

CHANCES ARE, you've been yelling at your computer games for years. Now, if you strap on UR Gear, the games will obey. The headset recognizes 20 words for performing simple tasks. You navigate by moving your head. A receiver plugged into the computer's serial and game ports tracks and relays your movements. For "twitch" input, like rapid firing, a handheld controller is included. Price: $99. Video Computers, Via Antonelli, 36 Torino, Italy. *www.union-reality.com*

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Not Just Show Biz

BUICK HINTS that it may join in the sport-utility mania, displaying the Signia concept car, a cross between a conventional station wagon and an SUV. Its bulbous shape is based on the current Park Avenue chassis, with four-wheel drive. A powered panel extends out the back for short hauling, and the rear hatch can be removed to fit tall items.

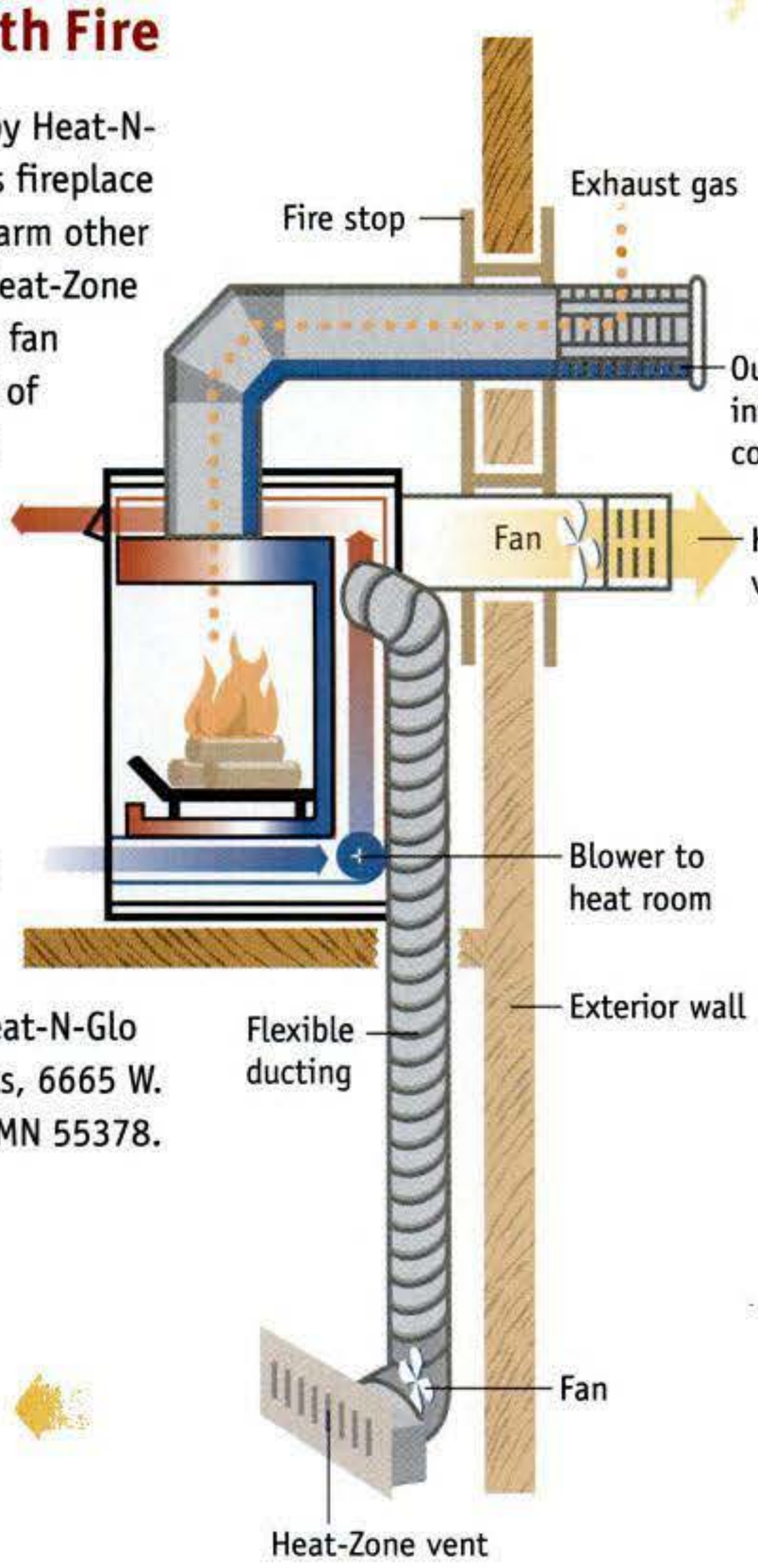
Field Scope

WEIGHING A mere 23 ounces, Nikon's Naturescope 20X portable microscope makes field work easy. A detachable plate serves as a stage for solid specimens, and a built-in cup on the reverse side holds liquids. Without the plate, the Naturescope **can** be used to observe objects as far as 50mm away. Price: $672. Nikon Inquiry Response Center, 28 Brandywine Dr., Deer Park NY 11729. *www.nikonusa.com*

Heating with Fire

ALEX REARDON

HEAT generated by Heat-N-Glo's 6000XLT gas fireplace can be used to warm other rooms with the Heat-Zone system ($239). A fan draws hot air out of the fireplace and distributes it through flexible ducting. For warm climates, the Heat-Out system ($199) vents outdoors, so you can enjoy the flame without sweltering. Price: $1,649. Heat-N-Glo Fireplace Products, 6665 W. Hwy. 13, Savage MN 55378.



Camera-like Camcorder

THE TINY CANON ZR digital video camcorder has a horizontal orientation—$4^{11}/_{16}$ by $3^{3}/_{8}$ by $2^{3}/_{16}$ inches—for a feel that's more like that of a still camera. The 19-ounce camcorder's 2.5-inch color LCD pops out and can be rotated 180 degrees. A clip-on shade turns the LCD into a viewfinder. Price: $1,999. Canon U.S.A., One Canon Plaza, Lake Success NY 10042. *www.canondv.com*

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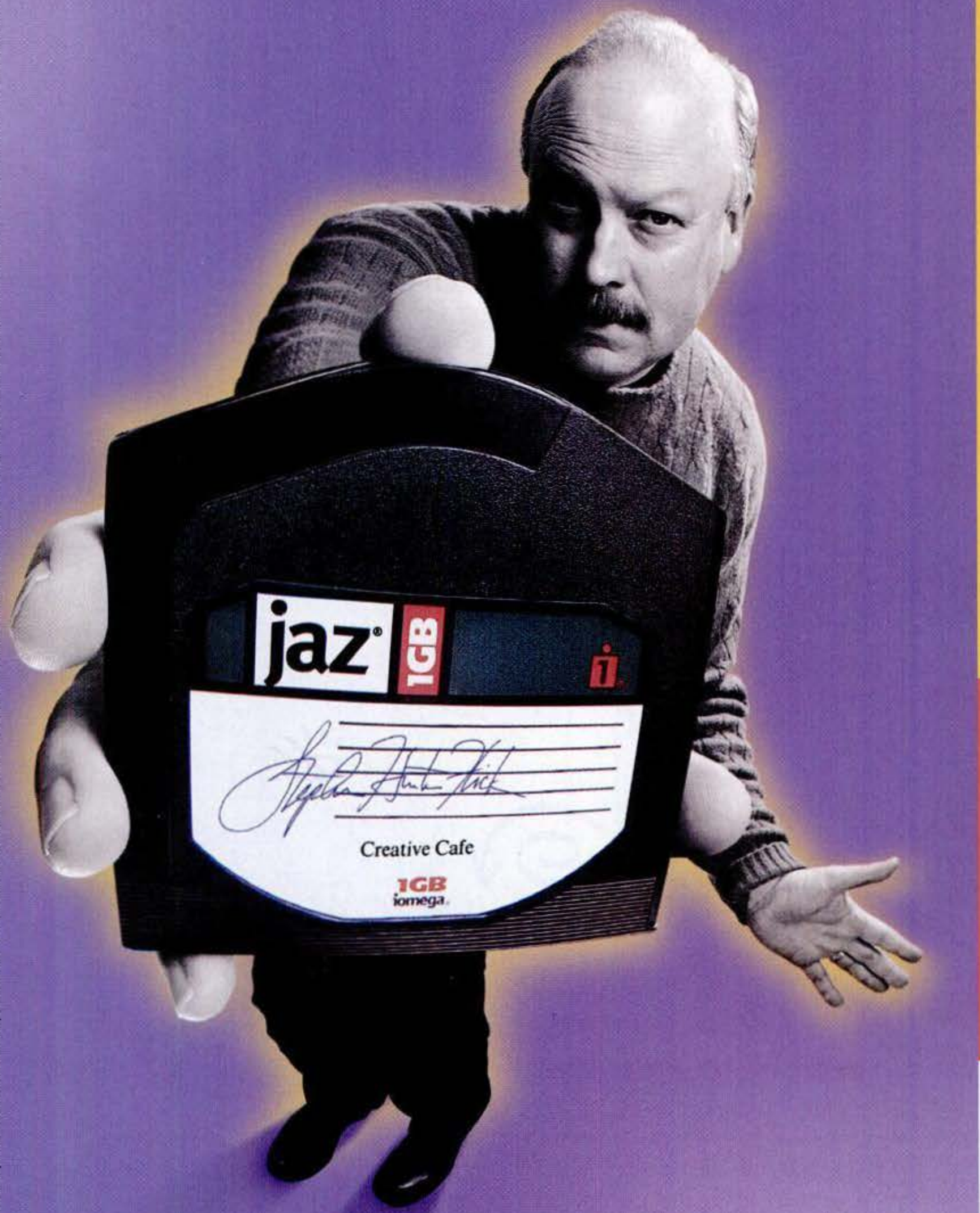
"How I fit 1 speeding downtown bus,
a crippled lunar lander, and
5 car-tossing tornados into a
4 INCH SQUARE."



STEPHEN HUNTER FLICK
Sound Designer

As the two-time Academy Award-winning sound effects specialist whose work includes films like *Speed*, *Apollo 13*, and *Twister*, Stephen Hunter Flick works with major movie studios creating some of film's most incredible effects. From compiling over 2,000 sound files to create a massive tornado to transporting or even cutting straight to digital picture, Stephen's work takes big space. With his Jaz drive and its sustained transfer rate of up to 6.62MB per second, he can back up 1 whole gigabyte in as little as 10 minutes. The Jaz drive not only gives him the flexibility to run applications and files straight from disk, it's also compatible with nearly all operating systems. So while Stephen's work is truly larger than life, it still fits neatly into his pocket

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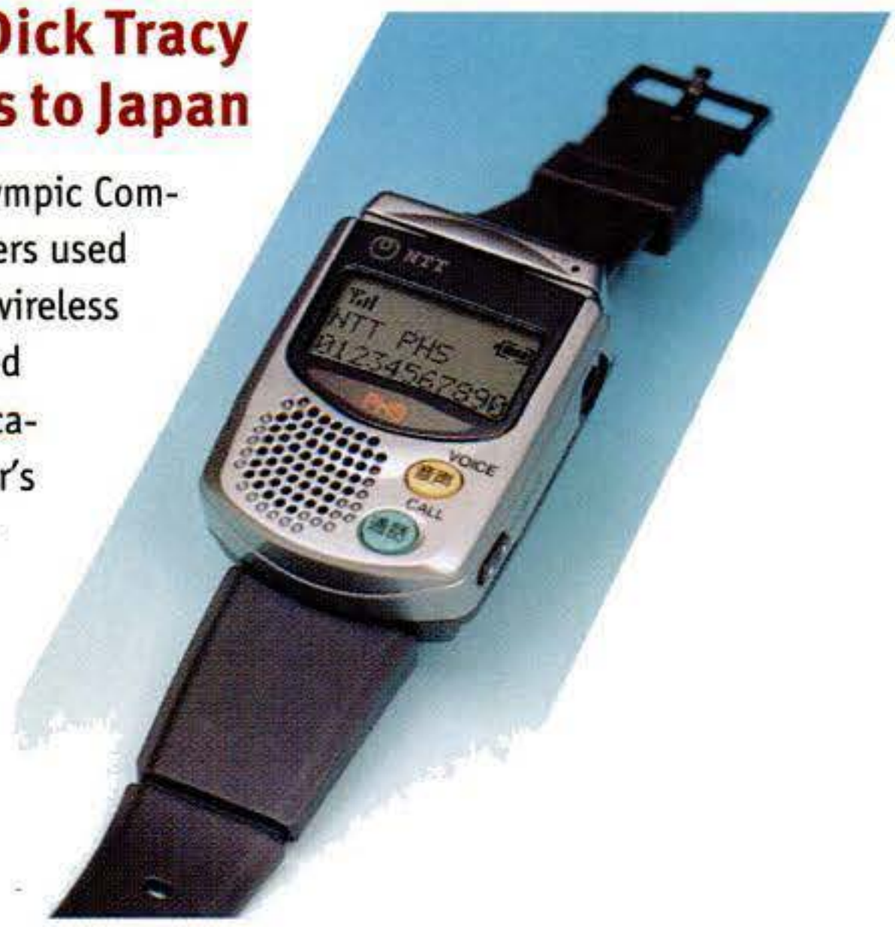
Compact Rack

THE HARMON/KARDON Festival 80 is a Dolby surround sound system in a small, elegant package. Amplification for the system's five speakers is housed in the subwoofer's cabinet. And the compact rack includes a seven-CD changer and an AM/FM radio that displays song titles and other broadcasted Radio Data System information. Price: $2,199. Harmon/Kardon, 250 Crossways Park Dr., Woodbury NY 11797.

Dick Tracy Goes to Japan

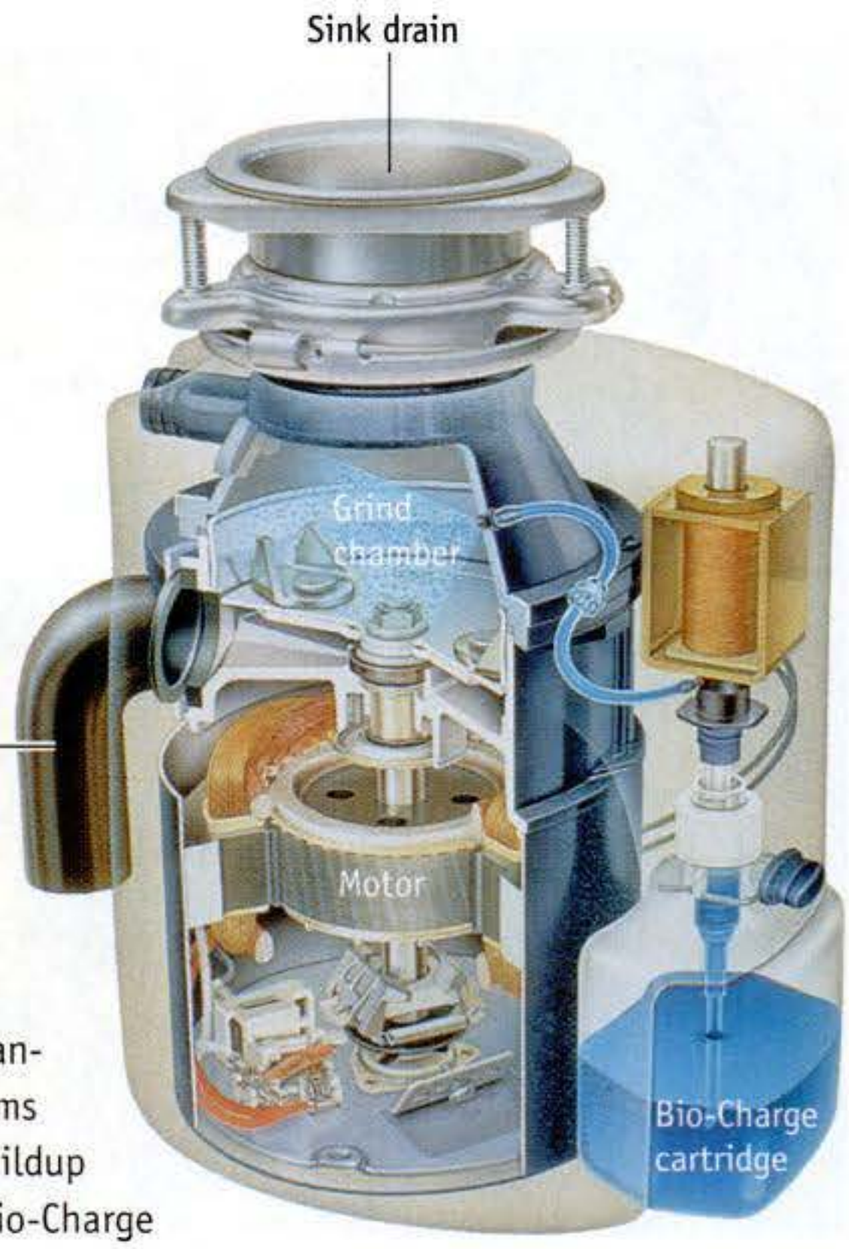


NAGANO Olympic Committee members used this prototype wireless wrist phone, called Wearable Communications, during this year's Winter Games. The 1.6-ounce phone provides 60 minutes of talk time with its lithium-ion battery. There are no plans yet to introduce the phone.

Teflon Socks

TO HELP STOP blisters and calluses from forming, Blister Guard socks won't stick to your feet. Fibers of slippery DuPont Teflon are woven into the heel, toe, and pad (dark thread, inset) of the socks. The Teflon lets the socks glide over your feet, virtually eliminating the friction between your feet and shoes. The Blister Guard system is available under various store and brand names. Price: $5 to $15 a pair. PTFE, 125 Melbourne Dr., Athens GA 30604.

Septic Solution



YOU WON'T HAVE to worry about food clogging your septic tank with In-Sink-Erator's Septic Disposer. The garbage disposal system comes with a cartridge that injects enzyme-producing microorganisms into the grind chamber. These microorganisms digest food and other wastes, reducing sludge buildup and accelerating the process of decay. Each $9 Bio-Charge cartridge lasts about four months. Price: $189, plus installation. In-Sink-Erator, 4700 21st St., Racine WI 53406.

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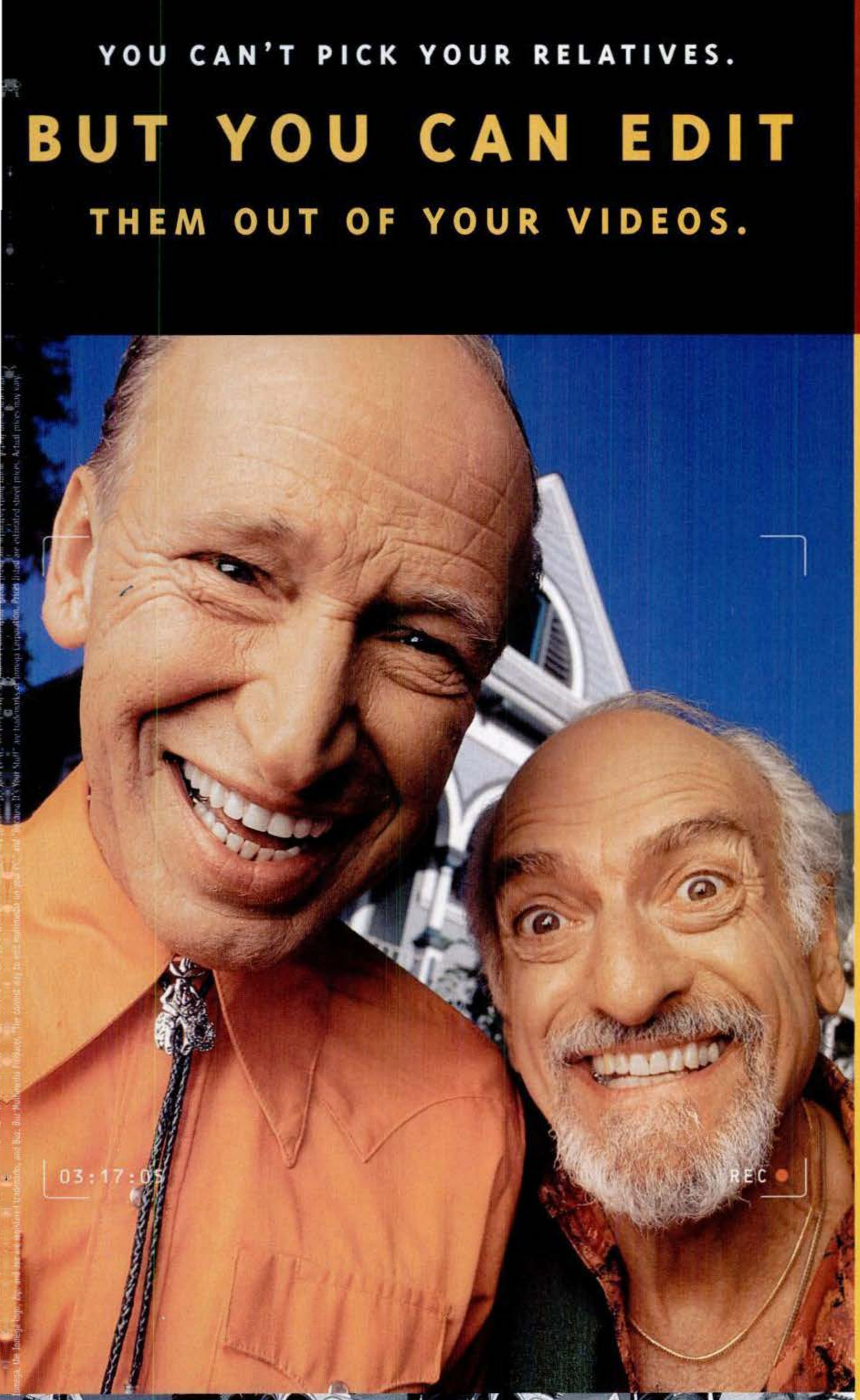
THEM OUT OF YOUR VIDEOS.



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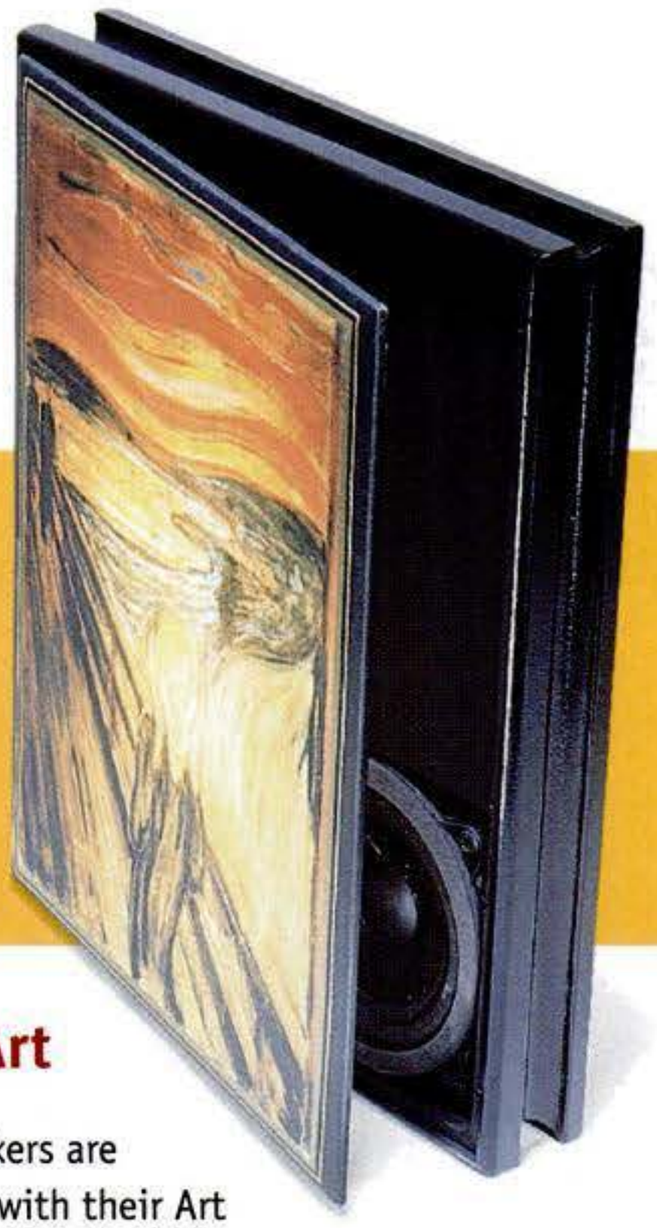
String-Dispensing Trimmer

THE BLACK & DECKER Grass Hog string trimmer dispenses string as needed. Inside the trimmer head, the weight of the string is balanced against a lever. As the string shortens, it loses weight, causing the lever to drop and about 1 inch of replacement string to shoot out. The weight of the longer string then forces the lever back up. Price: $59. *www.blackanddecker.com*

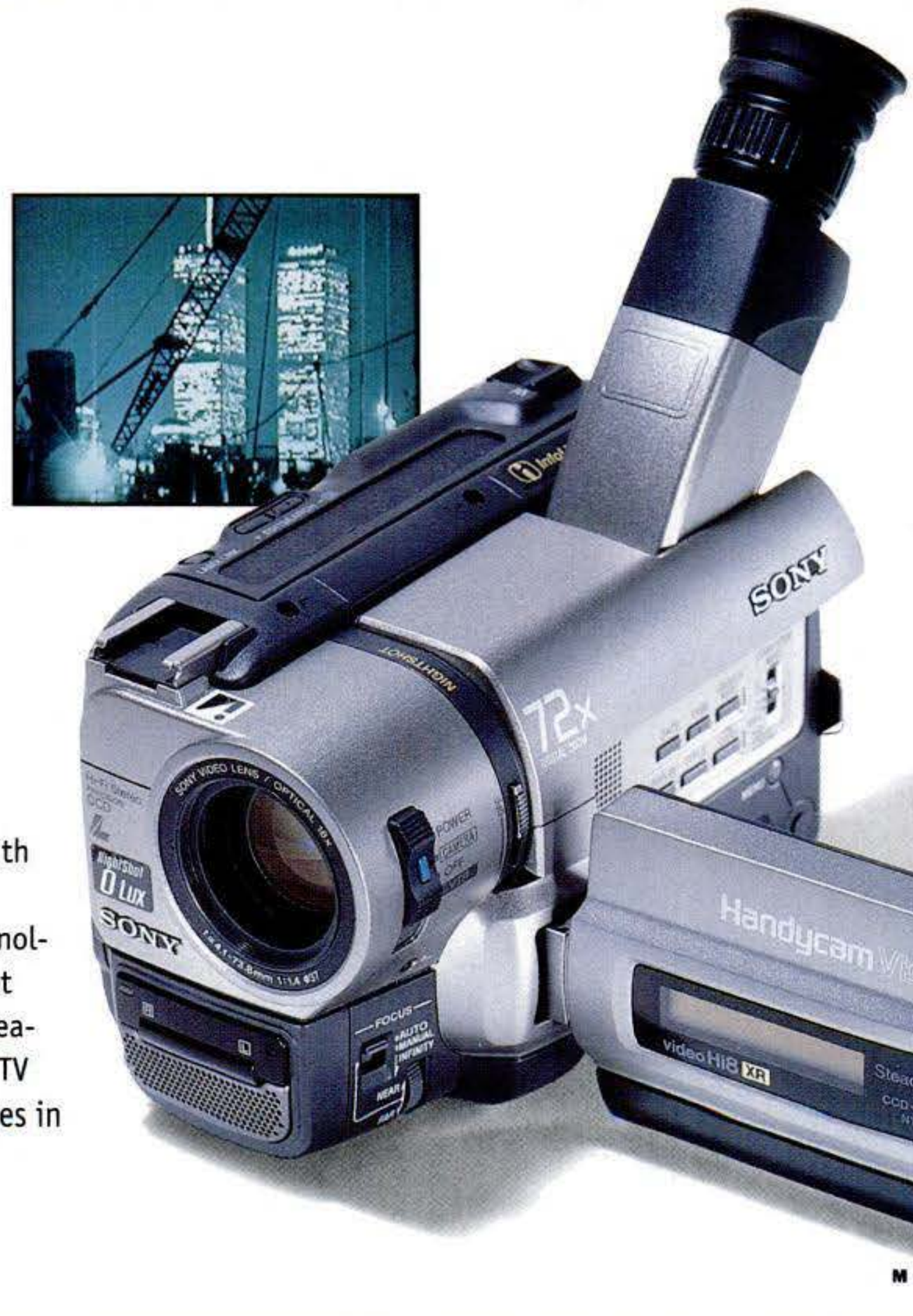


Speakers as Art

THE GEKKO FLAT speakers are as pretty as a picture with their Art Gekko colorfully printed grills. And at less than 2 inches deep, they look like framed artwork when they're hung on a wall. The speakers come in three sizes: 9 by 11, 11 by 14, and 18 by 24 inches. Price: $500 to $2,000 depending on size and grill. Noise Cancellation Technologies, One Dock St., Suite 300, Stamford CT 06902. *www.nct-active.com*

Digital Pro

CANON AND KODAK have teamed up to produce one of the most advanced professional digital cameras ever. The Canon EOS D2000 and Kodak DCS 520—the only difference is the name—combine Kodak's two-megapixel (1,736- by 1,160-pixel resolution) CCD sensor and color calibration with Canon's EOS lense. They also feature a 1.8-inch color LCDscreen. Price: $14,995. *www.kodak.com/professional* or *www.usa.canon.com*



A Shot in the Dark

SHOOT THROUGH even the darkest nights with Sony's Handycam Vision Series camcorders equipped with NightShot. The infrared technology lets you capture images as far as 10 feet away (shown on Model CCD-TRV85). Other features include a wireless connection to your TV and a 1-hour lithium-ion battery that charges in 15 minutes. Price: $799 to $1,399.

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Per Day, You'd Need A

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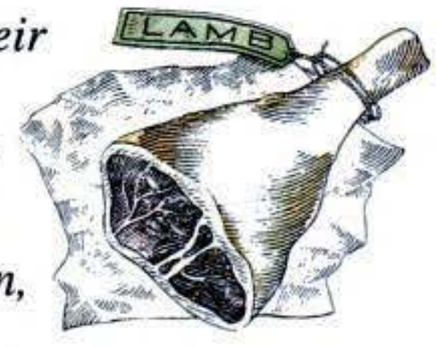
On average, puppies in their first year of life grow up ten times faster than humans. (And you thought your childhood went fast.) So wouldn't it make sense to feed them a diet filled with extra protein as well as other wholesome nutrients? We thought so, which is how we came up with Purina O·N·E® brand Puppy Formula. The first ingredient is real lamb. And in case you didn't know it, lamb is a great source of protein that, along with other high-quality ingredients, makes Purina O·N·E especially easy to digest. So their growing bodies can use every bit of the food's nutrition, which is important when you're going through adolescence at the speed of light. For a free sample, call 1-800-787-0078, ext.44.



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NEWSFRONTS

SCIENCE & TECHNOLOGY

EDITED BY DAWN STOVER

Proteus airplane with antenna on its belly

AVIATION

Very Low Orbit

AEROSPACE ENGINEER Burt Rutan's latest aircraft is nearing completion at a hangar in Mojave, California. Called the *Proteus*, the 6-ton plane has a tail-first design with twin tailbooms, and slender gull wings spanning 95 feet. The all-composite *Proteus* looks conventional by Rutan standards, but its mission is unique.

Angel Technologies, the St. Louis company funding the development of the *Proteus*, intends to use the plane as a low-flying satellite to provide ultrafast telecommunications to big cities. With antennas as small and inexpensive as direct-broadcast TV satellite dishes, customers will be able to bounce signals off the plane's belly-mounted antenna rapidly enough for two-way videoconferencing, high-resolution image transmission, and other speed-hog applications.

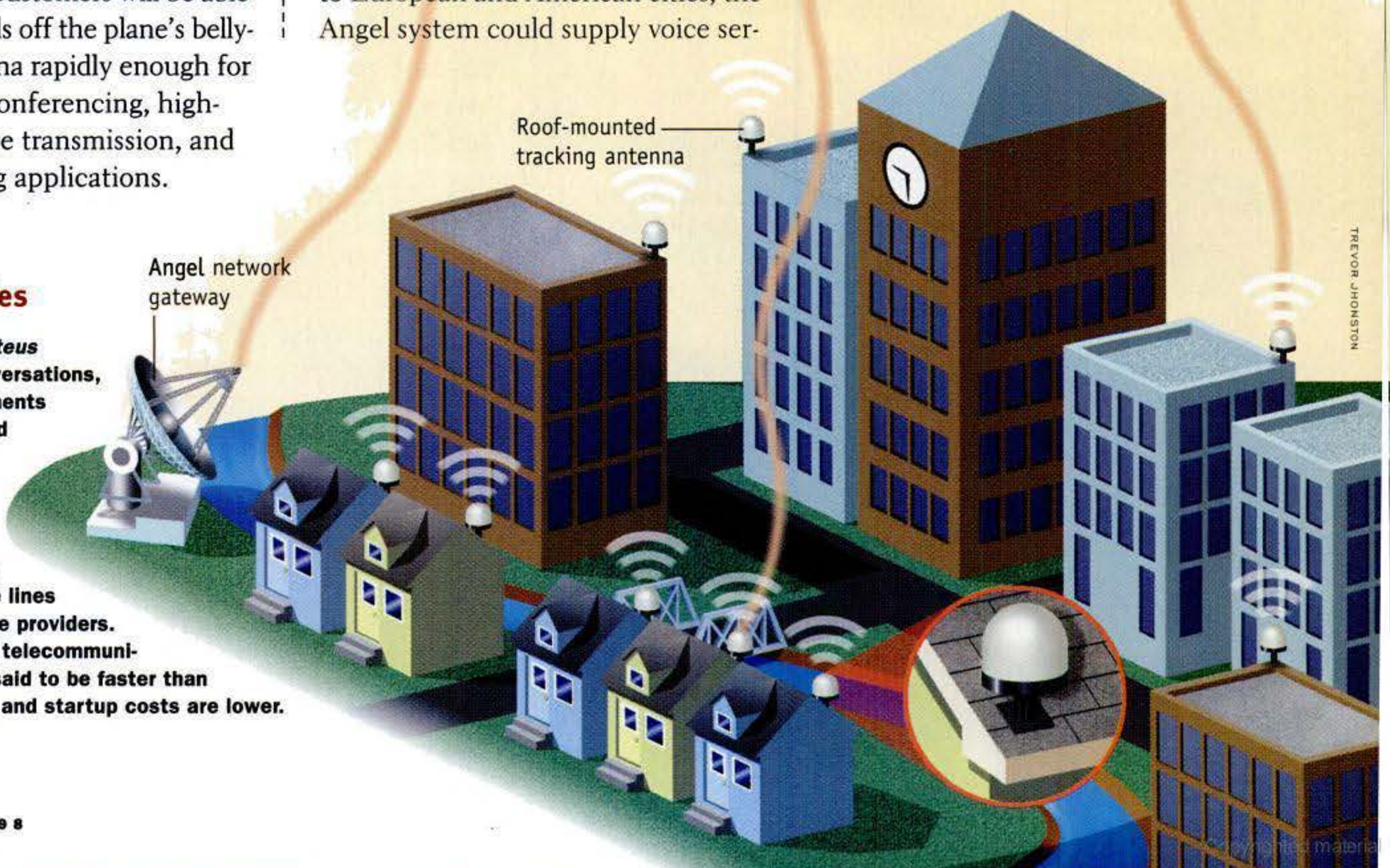
The airplane's twin Williams FJ44 turbofan engines will produce 10 times as much electrical power as a satellite's solar cells, and because the plane is closer to the ground than a satellite, signals travel faster with less power. The result is that the *Proteus* will relay data at a rate of 16 gigabits per second—100 times as fast as any existing satellite. The airplane is expected to cost less than $5 million, versus $100 million merely to launch a satellite, and its 1-ton electronics package can be repaired or upgraded on the ground.

Three airplanes could provide 24-hour service to as many as 500,000 terminals, depending on the average level of traffic, the company says. As well as bringing high-speed coverage to European and American cities, the Angel system could supply voice service to cities lacking a modern phone system. The first Angel network could be operational within a few years.

Built by Rutan's Scaled Composites company, the *Proteus* plane at the heart of the Angel system will have two pilots. The cabin includes a sleeping area, because the airplane can stay airborne for 18 hours. The plane will cruise at 52,000 feet, higher than other commercial traffic and above most weather.

Named after a shape-changing Roman god, the *Proteus* is designed to carry a variety of pods or antennas for a wide range of potential civil and military missions. Rutan thinks the plane may even be useful as a platform for launching reusable rockets into space.—*Bill Sweetman*

Flying in Circles



The high-flying *Proteus* aircraft relays conversations, images, and documents between homes and businesses within a metropolitan area. Subscribers reach outsiders through a gateway linked to telephone lines and Internet service providers. The airplane-based telecommunications system is said to be faster than a satellite service, and startup costs are lower.

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GEOLOGY

Moving Mountains

THE GIANT continental plates that make up Earth's crust typically move only a few inches a year, about the speed fingernails grow. Until recently, scientists measured the plates' movements by studying changes in the geologic record over millions of years. Now, with the help of Global Positioning System satellites, geologists can observe plate motion in real time.

In a recent study, a team of U.S. and Peruvian scientists led by geologist Seth Stein of Northwestern University placed GPS-tracking antennas at 43 locations all over South America to study the convergence of two massive plates over a two-year period. The researchers measured about 3 inches of motion per year. A small portion of that motion is pushing the Andes Mountains upward, at a rate of about 0.3 inch per year. About half of the motion is building up as stress along the boundary where the plates meet, and will eventually be released by earthquakes. The GPS measurements can help predict when the earthquakes might occur.—*D.S.*

NATURE

Blind Pursuit

CLAWS AT THE ready, the tiger beetle launches into a high-speed run after his prey. Suddenly, the beetle stops dead in his tracks. After a brief pause, the chase resumes. And then

The tiger beetle *Cincendela repanda* hunts its prey in stop-and-go dashes.

the beetle abruptly stops again.

What's going on? That's what scientists have wondered about the puzzling hunting tactics of tiger beetles. The beetles pause for only about a half-second, which is not long enough to give their legs a rest, if that were the problem.

Now entomologists at Cornell University have an explanation for the strange behavior: The beetles temporarily go blind. "If the tiger beetles move too quickly, their eyes don't gather enough photons [light] to form an image of their prey," says entomologist Cole Gilbert. "That is why they have to stop, look around, and go."

Even after stopping three or four times during a chase, the beetle still manages to overtake its prey. The insect races along at 0.5387 meters per second, or about 1.2 miles per hour. That doesn't sound impressive until you consider that it's the equivalent of a human running the 200-meter dash in about 2 seconds.

The researchers hope their studies of the beetle's photoreceptors, which gather photons of light to make images, will lead to better visual systems for robots. "You don't have to have the fastest optical sensor if you sample intermittently [like a beetle]," says Gilbert.—*M.D.*

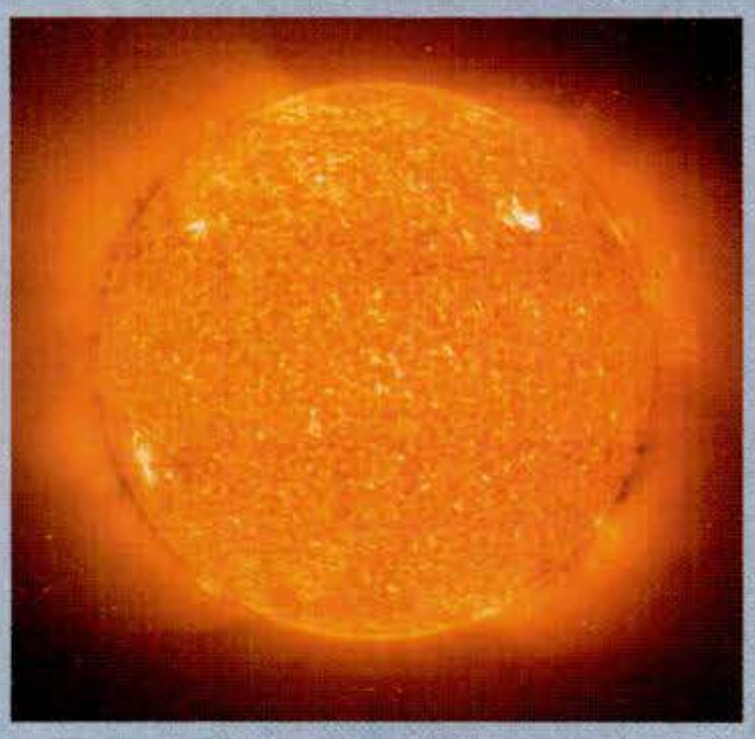
THE SUN

Solar Puzzle Solved?

AT THE CORE of our sun is a thermonuclear furnace where fusion reactions create the titanic energy that streams through the solar system and sustains life on Earth. The temperature at the sun's center is some 15 million degrees Celsius. The surface is a relatively cool 6,000°C.

But above the surface, in the sun's corona, the outermost layer of the sun's atmosphere, something inexplicable occurs. The temperature, first measured 55 years ago, is a blazing 1 million degrees or more. How can the corona be hotter than the sun's surface? Thermal energy does not normally move from a cooler area to a hotter one. For 55 years, solar astronomers have struggled to find an explanation for their observation.

Now findings from the Solar and Heliospheric Observatory (SOHO), a joint mission of the European Space Agency and NASA, may have solved the puzzle. Instruments aboard the craft reveal a rapidly shifting pattern of magnetic loops on the sun's surface, which correlate with brightenings of hot gases in the corona.



Instruments on the SOHO spacecraft photograph brightenings of the solar corona.

"We think we've discovered the fundamental process by which the corona is heated," says Alan Title of the Stanford-Lockheed Institute for Space Research in Palo Alto, California, "even though we don't know precisely how it works. Magnetic fields appear and disappear in areas the size of California within a few days. The energy they contain is about the amount that a thousand Hoover Dams would produce in a thousand years. When the fields collapse, they generate huge electric currents that act on the highly conductive corona. It's like the heat generated by a lightning bolt. There is more than enough energy to heat the corona."—*A.F.*

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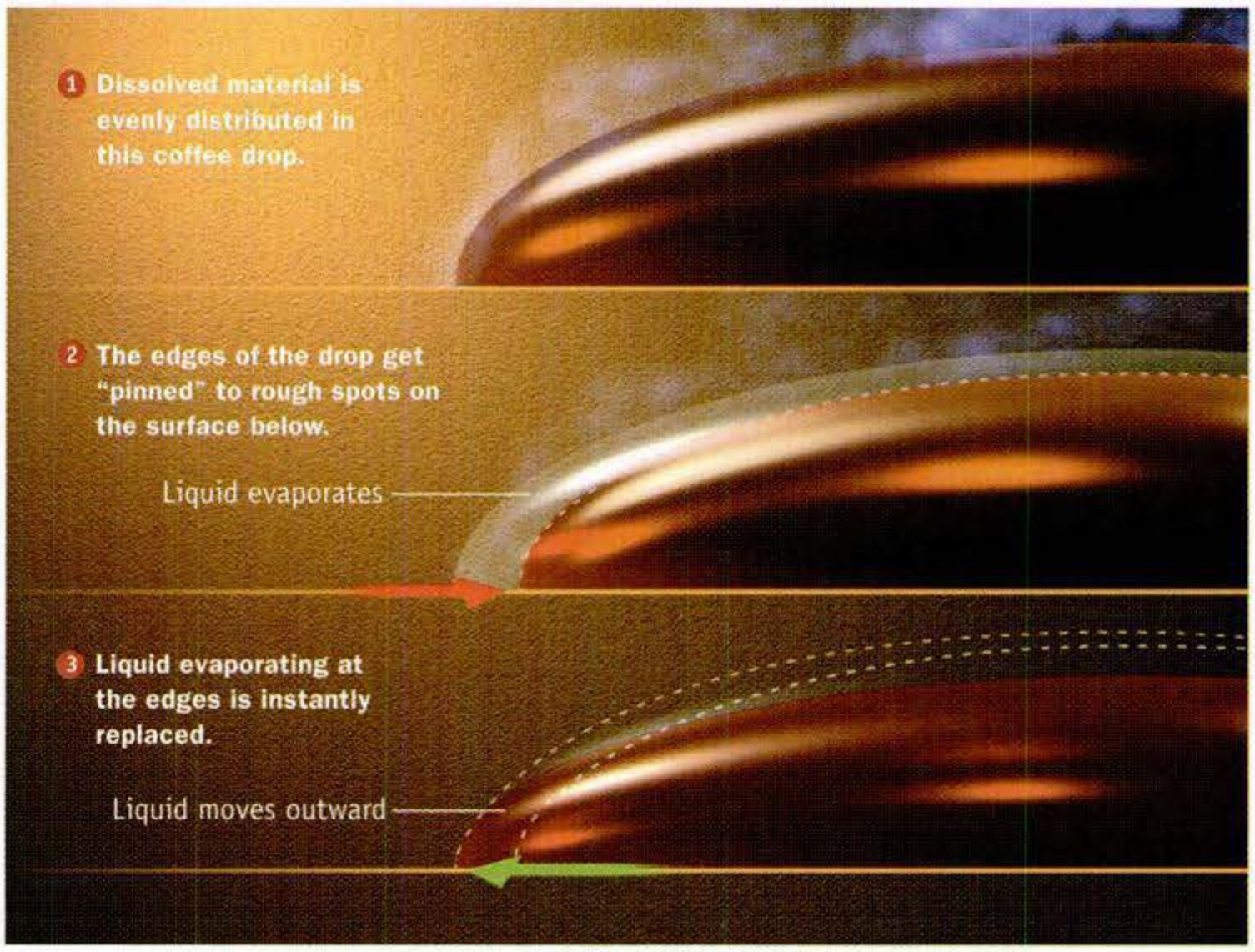
PHYSICS

Coffee Rings Explained


1 Dissolved material is evenly distributed in this coffee drop.
2 The edges of the drop get "pinned" to rough spots on the surface below.
Liquid evaporates
3 Liquid evaporating at the edges is instantly replaced.
Liquid moves outward

SLIM FILMS

WHY DO RINGS form after a spilled drop of coffee has evaporated? "There's something very bizarre about them," says physicist Sidney Nagel. "The stain isn't where you would have thought." After all, a drop is thicker in the middle, so why wouldn't more material be deposited there? When Nagel couldn't find an answer to this question, he recruited colleagues at the University of Chicago to help him research the problem. They learned something new about how liquids behave.

The team—including a mathematician, theoretical and experimental physicists, and graduate students—found that coffee gets "pinned" at the perimeter of a drop, where the liquid edge snags on microscopic rough spots in surfaces like countertops. As the liquid evaporates from the drop's exterior, more material is pulled outward to replace it. "That makes the pinning effect even stronger," adds Nagel. What's left: a dried ring.

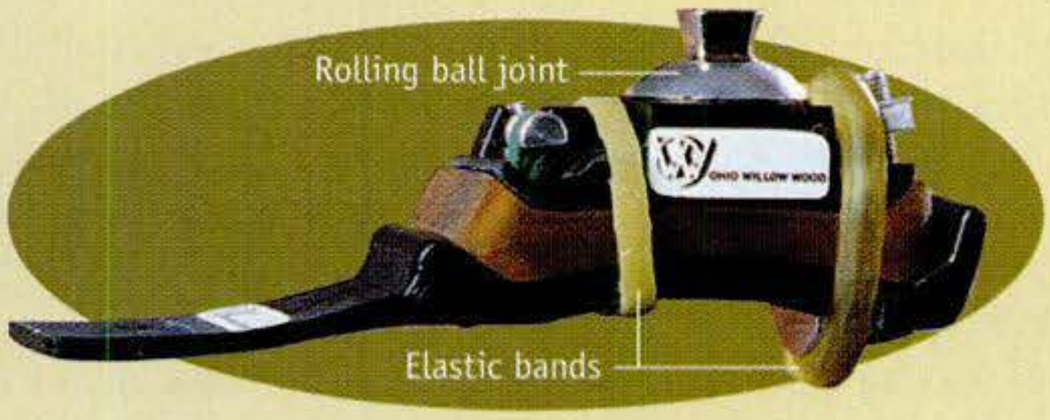
These rings form when any liquid dries, from water spots on china to dried paint "doughnuts" in a factory, so the finding has implications for industry. "Once you understand why something happens, you can figure out how to control it," says Nagel. One application he envisions is creating fine wires of gold, for electronic circuitry, from elongated droplets.—*Mariette DiChristina*

MEDICINE

A Step Forward for Peace

IN ONE OF THE most unusual examples of East-West collaboration since the end of the Cold War, scientists at two nuclear weapons laboratories are working together to build a better prosthetic foot.

The idea is the brainchild of Mort Lieberman, a researcher at Sandia National Laboratories in New Mexico. It all began at a meeting where Lieberman heard a physician discuss the contributions medical technology could make in Africa and Russia. "As soon as he mentioned Russia," Lieberman recalls, "I thought of getting Russian nuclear scientists to work on a prosthetics project, as part of the Initiatives for Proliferation Prevention." That program, supported by the U.S. Department of Energy, helps Russian nuclear weapons scientists find peacetime employment, so that they won't be tempted by Faustian offers from countries like Libya and Iraq.



A more flexible prosthetic foot is the goal of a peacetime collaboration between Russian and American weapons designers.

Lieberman's brainstorm has enabled eight materials scientists at Russia's notorious Chelyabinsk-70 weapons lab to focus their expertise on a prosthetic foot design patented by Tufts University professor Mark Pitkin. The foot will be the first to contain a rolling ball joint, rather than a pin joint, to more closely approximate the action of a real foot. That should make the device more acceptable to amputees, many of whom find existing prostheses uncomfortable.

"We're asking the Russians to look at everything that holds the foot together," says Jim Colvin, director of engineering for the Ohio Willow Wood Co. of Mt. Sterling, Ohio, which will license the prosthesis. For example, the Russians will select the optimal material for the foot's elastic bands, which must make initial movement easy but provide stability when stretched.

Funding for the collaborative project comes from the Department of Energy and the National Center for Medical Rehabilitation Research.—*Arthur Fisher*

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AUTOMOTIVE

EDITED BY DAN McCOSH

ALTERNATIVE DRIVE

GM's Clean Family

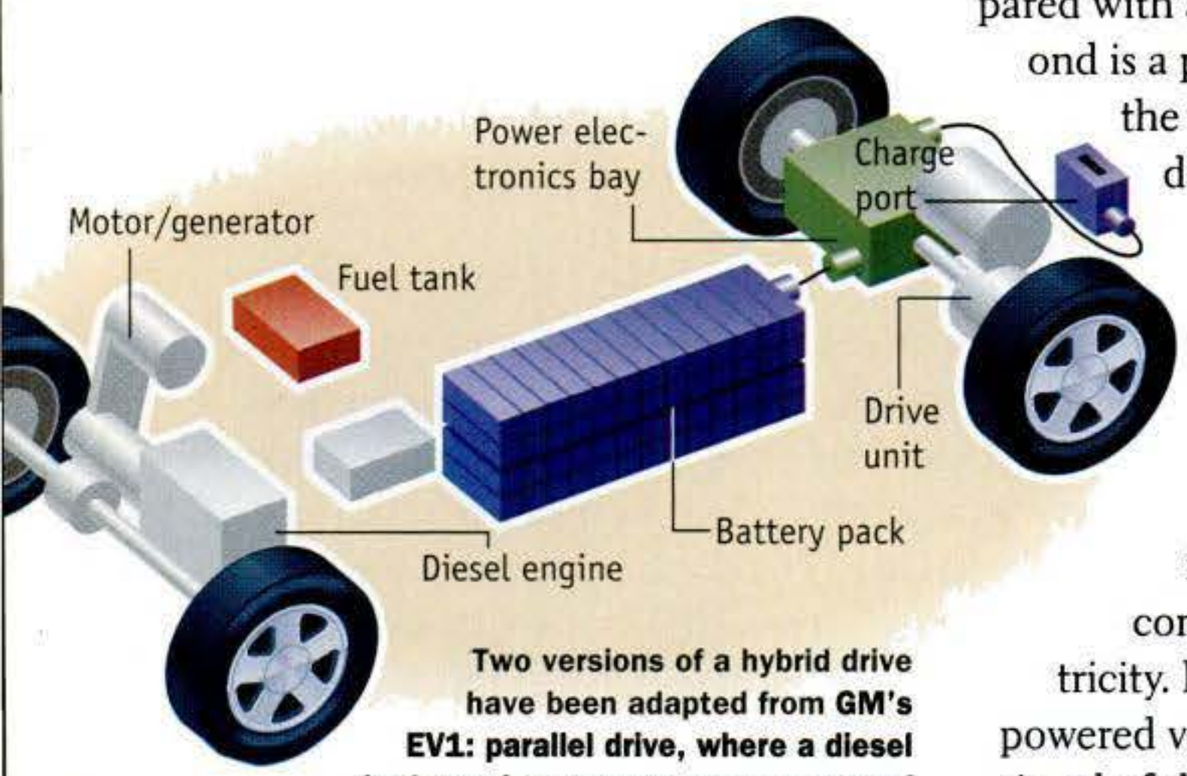
GM'S ELECTRIC car, the EV1, now provides the building blocks for a series of alternative-drive derivatives that use the basic EV1 electric-drive system as the primary propulsion.

Slow sales have hindered production plans for the EV1, but the experience gained in building the EV1's AC induction motor and transaxle combination has lead to significant cost reduction, the company says. GM notes that its production of the EV1 powertrain continues to lower the price tag for electric drive, and predicts that the company will be able to achieve the one-third reduction in cost that will enable its drives to be competitive with gasoline engines.

The EV1 is powered by lead-acid batteries, soon to be supplanted by an optional nickel-metal-hydride power pack. Range still is limited, and research continues on alternative drive systems. GM recently unveiled a total of four experimental power systems, all showcased in prototype EV1 cars, displacing the originall all-electric drive—although three depend on the original EV1 electric transaxle. The four drive systems are under development in GM's advanced-research program.

One is a series hybrid, with the battery charge maintained by a lightweight gas turbine generator. This dramatically extends the range compared with an all-electric car. A second is a parallel hybrid, using both the EV1 electric motor and a direct-injection diesel. The two work in tandem to recapture energy lost to braking, while GM claims acceleration would be quicker than that of a BMW. Third is a fuel cell car, which converts hydrogen to electricity. Fourth is a natural-gas-powered version, the most conventional of the lot. A 1.0-liter turbocharged engine provides the equivalent of 60 mpg, with good acceleration and a 400-mile cruising range.

The basic concepts demonstrated mirror work done at other companies, but GM says its electric-car experience can lead to significant cost reductions of heretofore expensive components, paving the way for producible alternative-drive cars starting in the year 2000.—*D.M.*



GREG MAXSON

Two versions of a hybrid drive have been adapted from GM's EV1: parallel drive, where a diesel is the main power source or a way of recharging the battery (above); and a series drive—a turboalternator charges the battery (below.)

PREVIEW DRIVE

Grander Grand Am

LONG A STAPLE of the small-car universe, Pontiac's 1999 Grand Am metamorphosizes into a credible midsize sedan, with a coupe derivative on the same chassis. The result is a vehicle that retains its sporty feel while gaining appeal as a car for larger families.

The 1999 Pontiac Grand Am embraces familiar styling on a new chassis.

An expanded 107-inch wheelbase puts the Grand Am in the company of today's Accord and Taurus midsize cars. The stiff chassis reduces interior noise and aids ride control.

Initially, the Grand Am will be launched with a 2.4-liter 150-horsepower four-cylinder engine and an optional 3.4-liter 170-hp V6. A high-output V6 will be added later this year. The higher torque of the V6 is noticeable in highway passing.

A hydroformed engine cradle is bolted to the frame, and a new trilink, fully independent rear suspension replaces the old torsion beam. The new suspension/chassis combination keeps the rear end planted solidly on uneven pavement.

This new Grand Am has a roomy rear seat, and a legible if slightly overstated instrument panel. The seats now are supportive enough for long drives.

With these changes, the Grand Am has matured into a pleasing, well-rounded package with a solid feel, whether you're slamming the doors or out on the highway. And its base price of below $17,000 is highly competitive.—*D.M.*

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ENGINES

New Diesels for SUVs

New, lightweight diesels are aimed at future light trucks and sport-utilities.

DETROIT DIESEL, one of the largest manufacturers of heavy-duty truck diesels, recently announced three new light-duty diesels intended for light trucks and sport-utilities.

Small diesel engines peaked in popularity in the late 1970s in the United States during the energy crisis, then declined as fuel prices dropped. Problems with emissions, particulates, and noise accelerated the decline in this country. Meanwhile, light diesels in Europe, encouraged by tax policies and high gasoline prices, advanced in both passenger cars and light trucks.

Detroit Diesel recently expanded its small diesel line to six engines. A new series of small direct engines ranging from 1.4 to 4.2 liters are under development. These use electronic fuel control, common-rail fuel injection, and a new kind of injector that squirts a small amount of fuel to begin the combustion process, with the main injection milliseconds later. This dramatically reduces the knocking sound of a direct-injection system.

The broad range of engines could have significant impact on fuel consumption of light trucks, notes Detroit Diesel.—*D.M.*

PREVIEW DRIVE

Pint-Size Perfection

DESPITE THE it-takes-a-second-glance-to-tell-that-it's-new styling, the 1999 Miata is a stem-to-stern redesign—all-new sheet metal, stiffer chassis, wider track, revised front suspension geometry, more power, and about the same curb weight.

These changes all add up to a better Miata—more eager, more agile, and easier to manage in quick maneuvers. The new Miata is also a bit quieter inside; the headlamps no longer pop up; glass replaces plastic in the convertible top's rear window; and now there's storage space under the rear deck lid for a couple of golf bags.

It has the same 1.8-liter twin-cam 16-valve four-cylinder engine, but now yields 140 horsepower and 119 foot-pounds of torque, compared with 133 and 114 for the previous generation.

We had an opportunity to barnstorm the byways of the Big Island of Hawaii in the new car, as well as wring it out on a nearby airport autocross. And while the changes are subtle, it's a bit quicker and distinctly easier to herd through a slalom. The previous car's tendency to go into snap oversteer—sports-car-speak for sideways—has been reduced to manageable levels.

Manageable also applies to the price tag. The base model is expected to start at about $19,500, some $10,000 less than a basic BMW Z3. (The Miata also is quicker than the Z3 four-cylinder.) With a top-of-the-line leather edition, it maxes out at about $27,000.

The bottom line: The Miata still is pure sports car, still delightful, and still the *only* sports car that can reasonably be called affordable. If you've been waiting for this one, we think you'll find it well worth the wait.—*Tony Swan*

The 1999 Miata's most visibly new feature is the headlamps, which no longer pop up for use.

DRIVETRAINS

Hands-Free Ferrari

THE EXOTIC F355 F1 Ferrari introduces one of the first true electronically controlled manual gearboxes for street driving.

The gearbox has been adapted from a transmission developed for Formula One race cars; its purpose is to retain the efficiency and durability of a manual gearbox while adding the speed of automatic shifting. Six hydraulic servos declutch, shift, and re-engage the clutch to make a shift. A computer intervenes to modulate the throttle to match the shift. The result is something like a robot doing the declutch-and-shift routine, instead of the driver.

The gearbox is controlled by two paddles located under the steering wheel—which allows quick shifting without taking either hand from the wheel. An automatic position is available as well to make the transmission act more or less like a conventional automatic would.

Shifts are quick and snappy, lacking the damping effect of a conventional hydraulic torque converter. The system does, however, add more racing spirit to the $144,000 D355 F1, for a meager additional $9,500 for the option.—*D.M.*

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PREVIEW DRIVE

Spreading Out the Luxury

IN LAUNCHING THE first all-new version of its 3 Series sedan in eight years, BMW has added a generous helping of advanced technology and luxury features originally introduced in its costlier models.

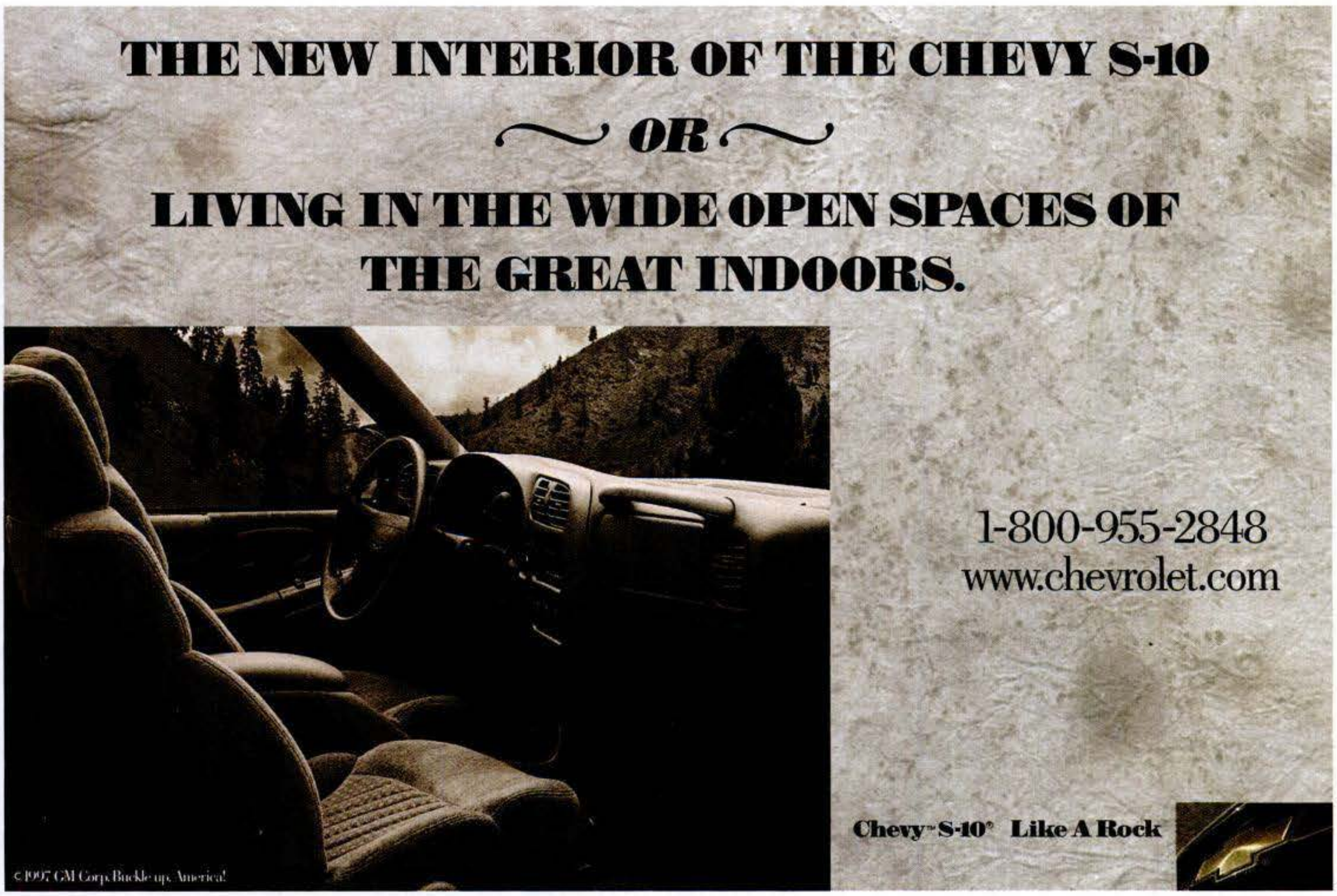
Consider safety, for example. BMW's distinctive headbag-protection system migrates from the 5 and 7 Series. Critical to this system is a tubular bag, mounted on the roof frame, that supplements the side bags. The new bag protects the head by expanding downward against the side window.

Then there's handling, where microprocessors guard against skids, spins, and other perils. The most sophisticated system, dynamic stability control (DSC), an option, helps maintain balance during cornering and swerving. DSC takes over—it can apply the brakes individually on any of the four wheels and reduce engine power—when it senses loss of control. ABS and traction control are standard. The electronic controls were especially reassuring during a stint on narrow, mountainous roads outside Jerez, in Southern Spain.

Both the 2.5-liter (323i) and 2.8-liter (328i) dohc 24-valve inline sixes come with BMW's variable intake and exhaust-valve timing system. This boosts torque at low speeds and helps decrease emissions. Because the car is 1.2 inches longer and wider than its predecessor, there's a bit more head- and legroom.

The sedans should be available by August. BMW notes that prices should probably be about 1.5 percent higher than last year's models and are expected to start just under $30,000 for the 323i.
—Bob Sillery

The BMW 3 Series' high-tech features add to the luxury image of its most compact line.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Material: *High Impact Polystyrene*
Height Open: *9 1/2"* *Height Closed:* *6"*
Power: *4, D Cell Batteries (not included), Alkaline Recommended*
Suggested Retail Price: *$19.99*

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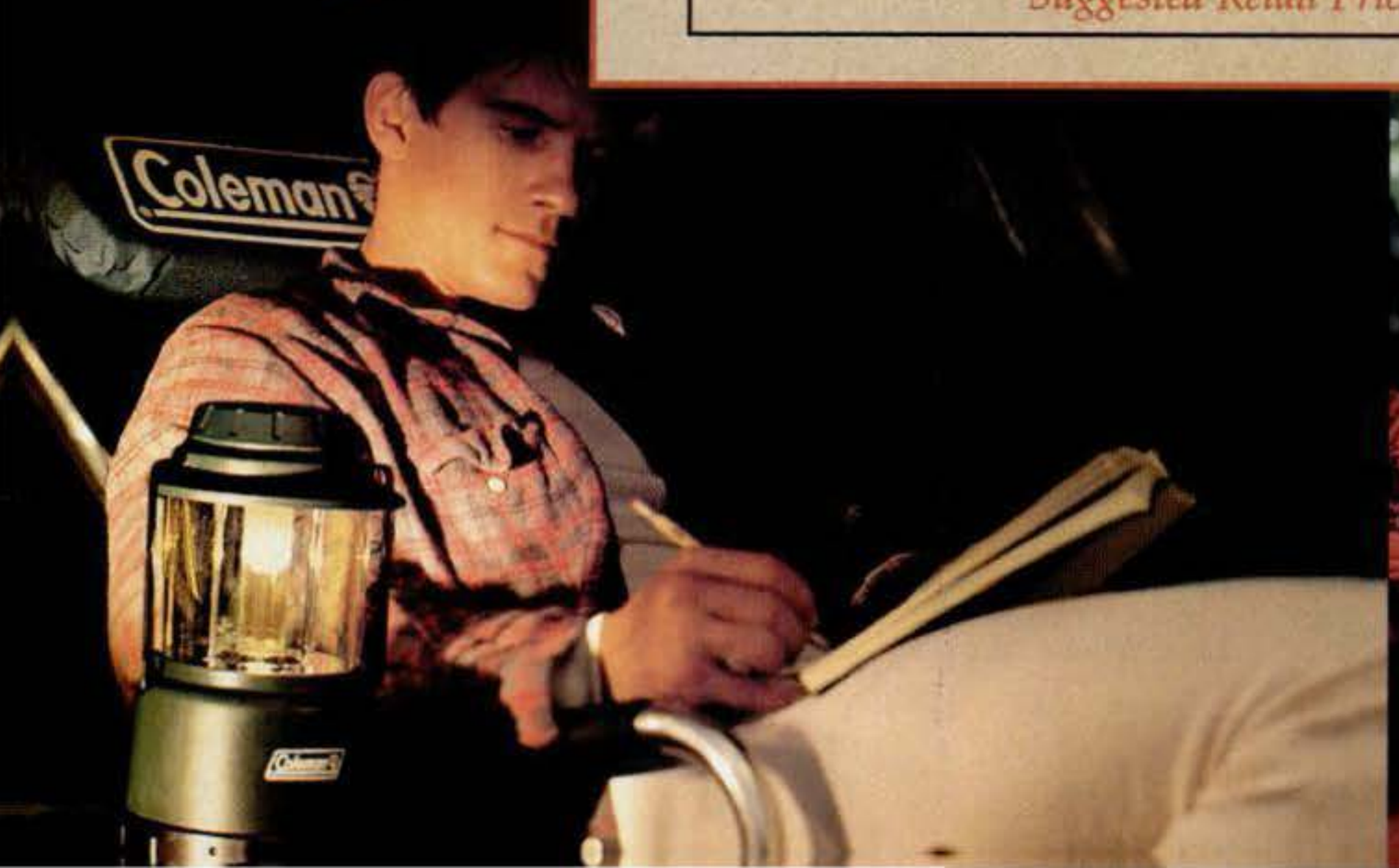

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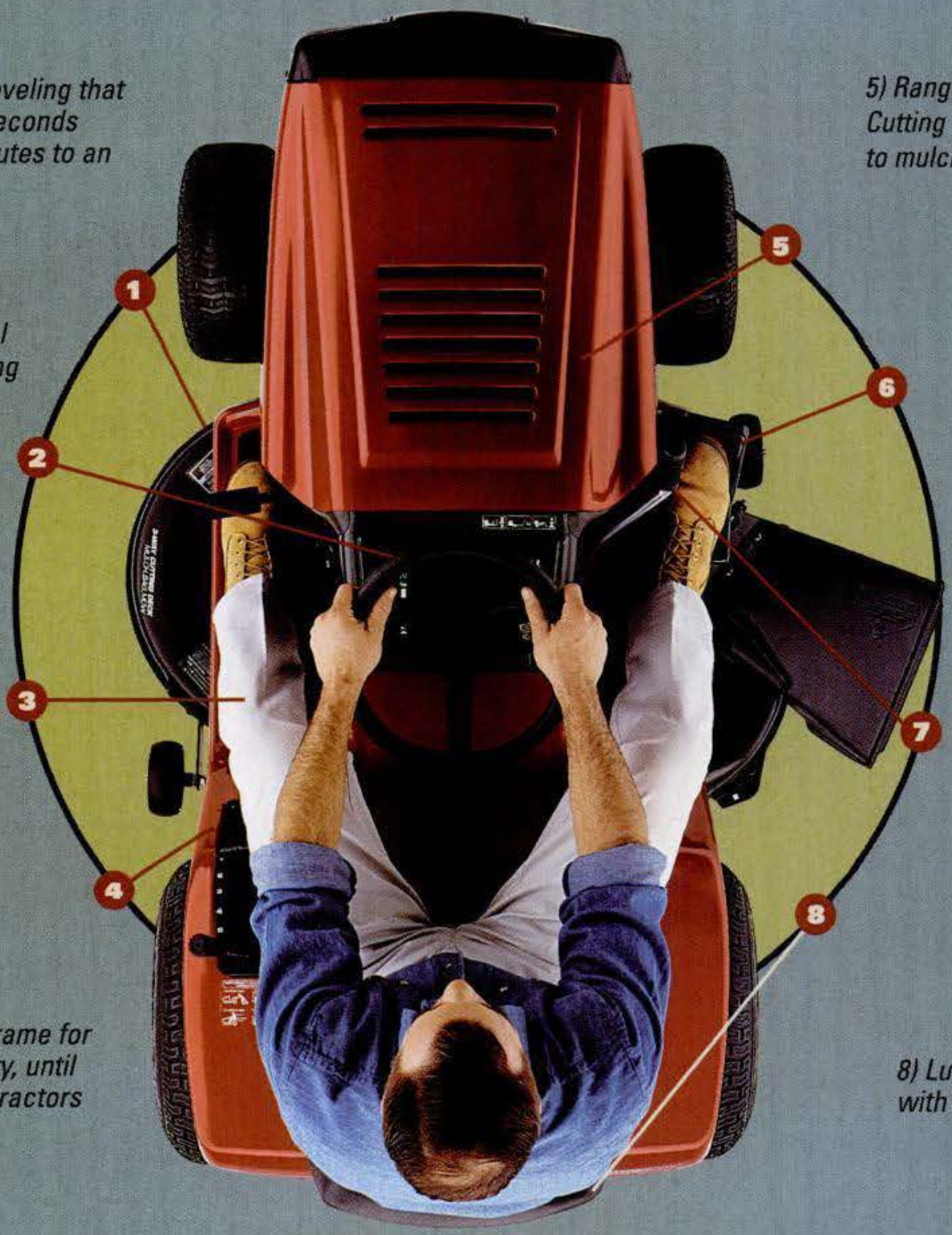
4) Solid Steel Rail Frame for strength and stability, until now only found on tractors costing much more.



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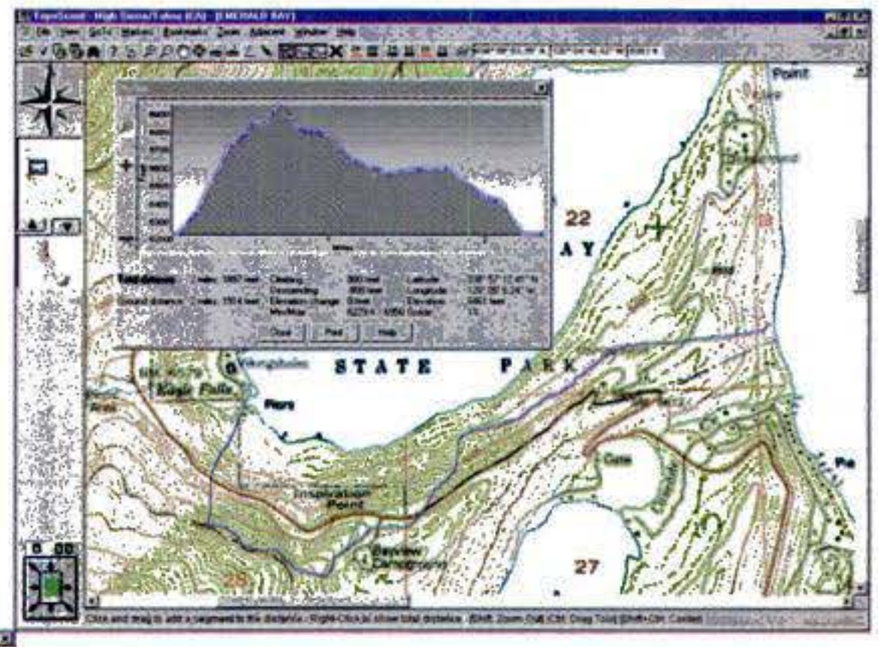
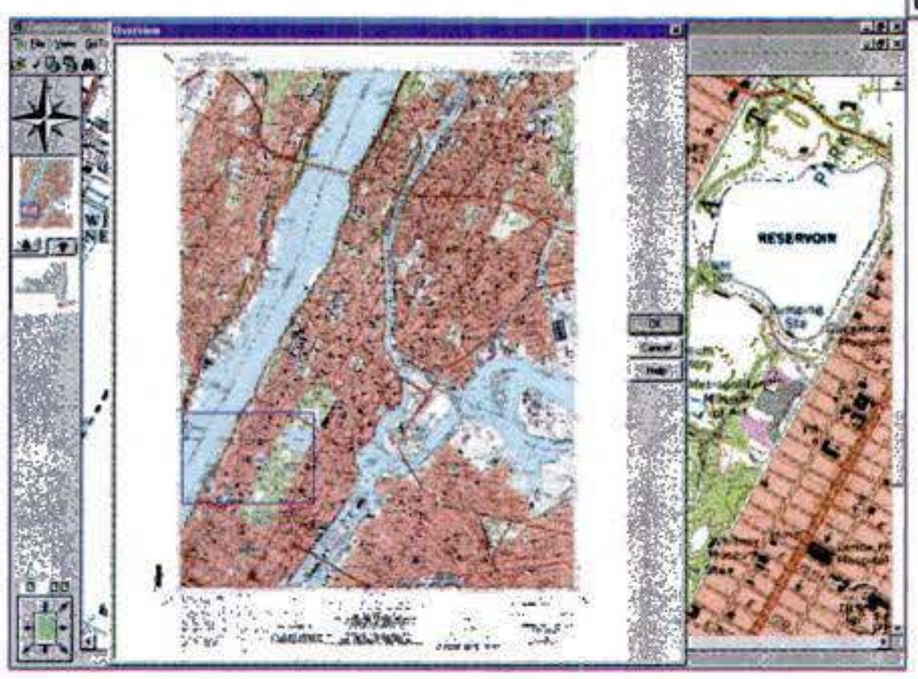
MAPPING

The Digital Landscape



TopoScout puts detailed topographic maps on your computer. You can scroll and zoom to four levels (below), as well as calculate coordinates, elevations, and distances (right). You can print the maps, too.



THE WORLD may not be flat, but you'd never it know from most maps—paper or digital. But digital maps are beginning to offer some relief, literally, from the flat-map doldrums.

Several companies are now selling digitized versions of the topographic maps developed by the U.S. Geological Service. Some are merely simple scans of USGS maps, while others are designed to be used with professional mapping software, sometimes known as geographic information systems. But at least one new series of topographic maps, TopoScout from Maptech (*www.maptech.com*), brings interactive digital USGS maps to consumers, whether they're hikers, campers, or real estate agents.

TopoScout lets you view its terrain maps in four zoom levels, with path elevation and line-of-sight profiling. You can enter GPS coordinates (latitude and longitude) and mark your location on a map, assuming you've got a laptop in your backpack or vehicle. You can also measure elevation, distance, and area, and place markers on the maps to note, perhaps, a favorite fishing spot or potential building site. All of the maps can be printed in color on standard PC printers.

TopoScout currently has maps for more than 20 states. Single CDs, which cover a small state (such as New Jersey) or a state region (such as San Francisco Bay), typically sell for $99 each. State or region sets of four or five CDs sell for $279 to $319. TopScout is available only for Windows PCs.—*C.O.*

WEB WATCH

EV Rides & Drives
Interviews
EV World interviews Marcel Boutin, vice president general manager for Bombardier's NV division about the company's new $7 199 neighborhood electric vehicle
Electric Bikes – The

EV World
www.evworld.com
Looking for a clean and green site peddling nothing but fresh air? EV World brings you the news, reviews, and shop talk on the latest electric cars and bikes. A database also lets you search for EVs available in your area.

Reader's Digest at Home
www.rdathome.com
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DOD Dictionary of Military and Associated Terms
www.dtic.mil/doctrine/jel/doddict
A handy guide for those who don't know "Saints" from "salted weapons."

Plastics Resource
www.plasticsresource.com
An interesting, if decidedly pro-plastic, look at this ubiquitous material and the environment.

Space Views
www.spaceviews.com
This online publication on space exploration includes news, launch schedules, and space-policy debates.

2000: Gifts to the Planet
www.nationalgeographic.com/features/2000
National Geographic peeks into key issues of the new millennium.

Alta Vista Translation Service
babelfish.altavista.digital.com/cgi-bin/translate?
Translating Web pages between English and several European languages.

National Kitchen and Bath Association
www.nkba.org
Helping you find the resources and professionals to tackle that redesign.

Real Computing
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Clips from Internet "radio" interviews with computer experts on hot topics.
—*Suzanne Kantra Kirschner*

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CD-ROMS

Spinning Your Own

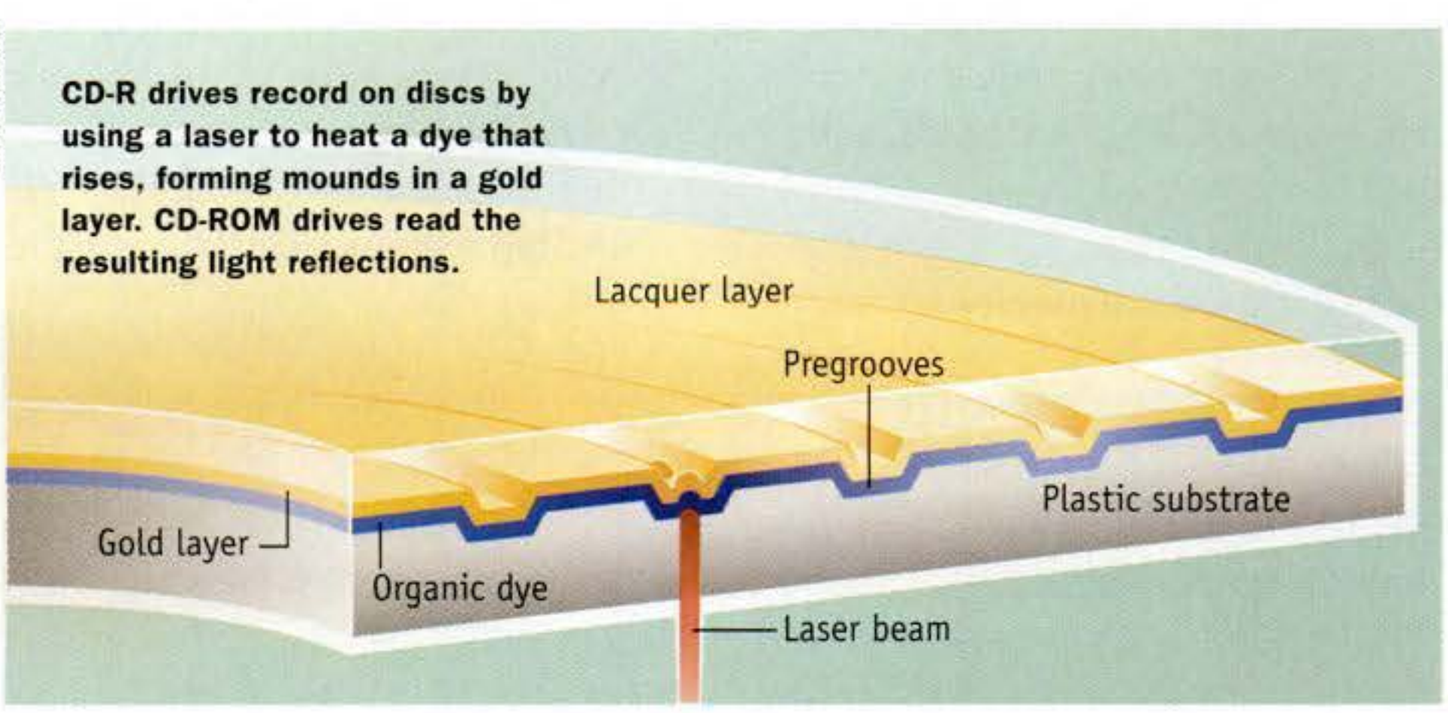
THE ONCE-fanciful notion of creating your own CD-ROM discs is beginning to look more like a do-it-yourself project.

Cost is one reason. Prices of compact disc recordable (CD-R) drives for PCs have plunged dramatically in recent months, to as little as $350. Hi-Val, JVC, Mitsumi, Ricoh, Smart & Friendly, Sony, and Yamaha are among those making inexpensive CD-R drives. Most of these drives now also include software such as Adaptec's Easy-CD Creator, which walks you through the process of putting data, music, pictures, or video onto a disc. And blank CD-R discs have fallen to a price of $1 to $2 per disc.

Why spin your own CD-ROM discs? For one thing, CD-R discs make for very cheap storage. Capable of holding as much as 650MB per disc, CD-R can archive your files for a fraction of a penny per megabyte. CD-R is also an easy, inexpensive way to exchange large picture, audio, or video files with friends and family, since CD-R discs can be read by any CD-ROM player (though not by some early DVD-ROM drives). You can also use most CD-R drives to copy music CDs (for personal use), or transfer music from tapes and records to CDs.

CD-R's primary limitation is that it enables you to record information to a disc only once—you can't erase. But newer CD-rewritable (CD-RW) drives, which let you record and erase as needed, now sell for between $500 and $800. The big drawback is that blank CD-RW discs still cost $10 to $15 apiece.—*C.O.*

GREG MAXSON

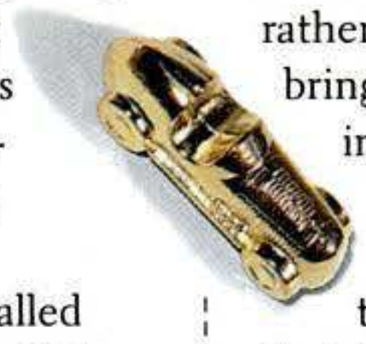


CD-R drives record on discs by using a laser to heat a dye that rises, forming mounds in a gold layer. CD-ROM drives read the resulting light reflections.

GAMES

Monopoly's Math

LIKE MANY PEOPLE, Thomas Friddell, a Boeing aerospace engineer, likes to play Monopoly. But unlike most, Friddell spends his lunch breaks at his computer, working out winning strategies for the game.



Using a math program called Mathcad, sold by MathSoft, Friddell has calculated the board game's probabilities, including the odds of landing on various Monopoly squares. Among his conclusions: Illinois Avenue sees the heaviest traffic. Players are least likely to land on Baltic Avenue. Three houses on a property, rather than four houses or a hotel, brings in the fastest return on your investment. Players roll sevens more often than any other dice combination, so wait until your opponents are roughly that close before buying houses.

Friddell's next task is to analyze an even more confrontational real estate game, Risk.—*Dawn Stover*

MICROPROCESSORS

Cranking It Up

EVEN AS PCs get cheaper, the speed of their microprocessors keeps right on getting faster. And new chips from Intel, AMD, and IBM make it clear that trend will continue.

Intel's new Covington chip brings the power of Pentium II to low-cost PCs.

By summer, Intel plans to be delivering two new, low-cost versions of its Pentium II processor to PC makers. The first, code-named Covington, will be a 266MHz version with no onboard memory, or cache, to help speed things along. It will be used mainly in PCs costing less than $1,000. The second, code-named Mendocino, will run at 300MHz and will have some onboard cache for slightly faster performance. It's bound for PCs costing $1,000 to $1,500.

AMD, meanwhile, is shipping a 266MHz version of its Pentium-compatible K6 chip, also intended for low-cost PCs. Its first customers include Compaq and IBM. Cyrix, another maker of Pentium-class chips, says it has similar plans for faster, cheaper chips.

The megahertz keep coming for Macintosh fans, too. IBM recently shipped a 275MHz version of its PowerPC 750 chip, and the company says it has prototypes of the 750 that run at speeds as high as 480MHz, with the capability to push the PowerPC to 1 gigahertz (about 1,000MHz) or more in the near future.—*S.K.K.*

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ELECTRONICS

EDITED BY FRANK VIZARD

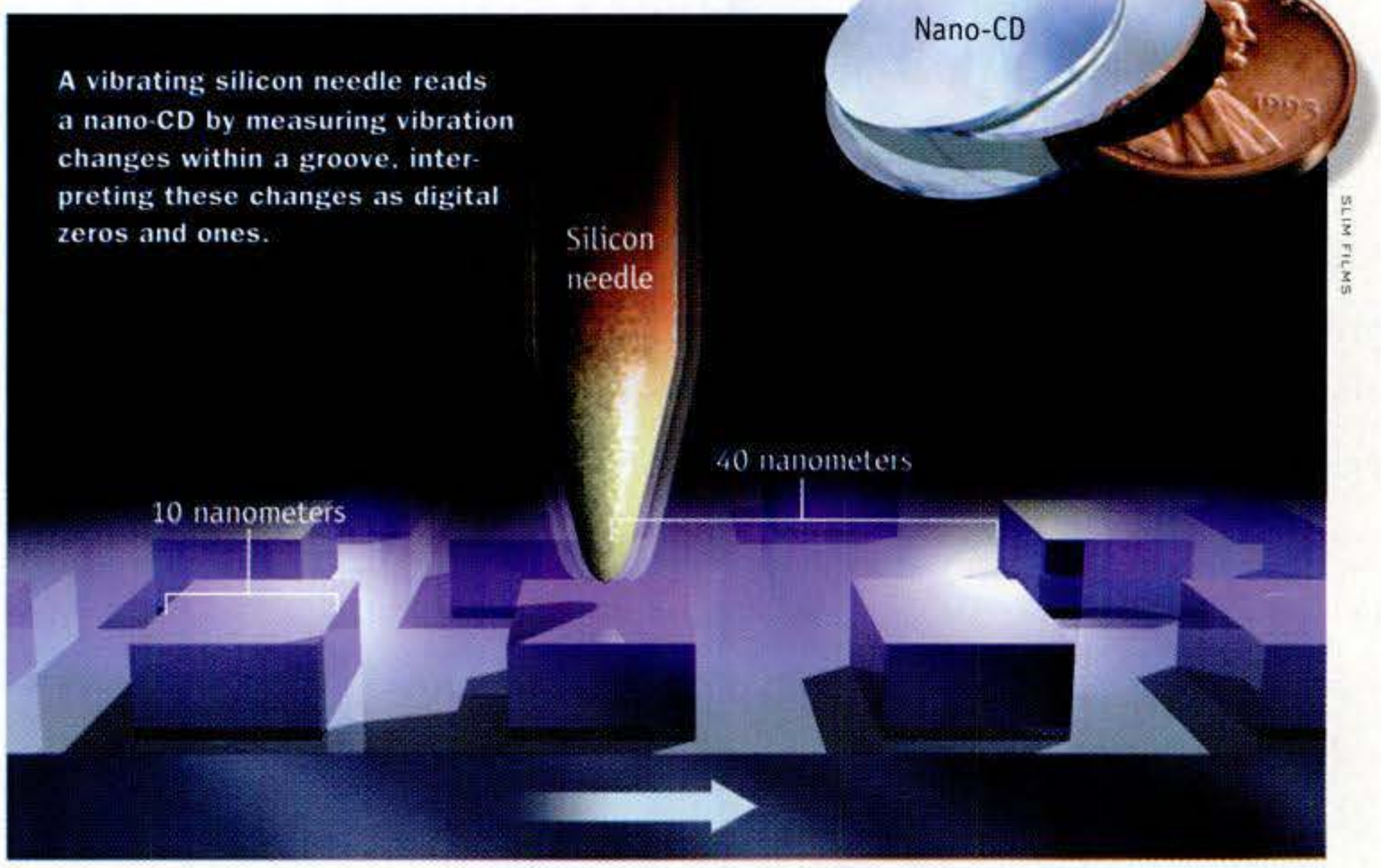
AUDIO

Penny-Sized CD

STEPHEN CHOU wants to shrink the size of your CD and video collection. At one-thousandth the size of a regular CD, his nano-CD could replace 30 of your music CDs with room to spare, he says. With 800 times the capacity of a standard CD, the nano-CD could revolutionize data-storage methods. "You can put all the information you need on a penny-sized CD," Chou says.

Chou, an electrical-engineering professor at the University of Minnesota, has developed discs that can store 400GB of information, instead of the 650MB on a regular CD and 4.7GB on a DVD. "Our density is 100 times higher than the best DVD," Chou states.

Before the CD is created, a data mold of microscopic grooves is fashioned. The mold is then stamped onto a softened, penny-sized polymer. The bits of data, recorded as tiny pits in the molding, are stored in grooves. The data bits are 10 nanometers (or billionths of a meter) wide and 40 nanometers apart.


A vibrating silicon needle reads a nano-CD by measuring vibration changes within a groove, interpreting these changes as digital zeros and ones.
Nano-CD
Silicon needle
40 nanometers
10 nanometers
SLIM FILMS

To read the information on the nano-CD, Chou developed a tiny silicon needle. "The needle itself is vibrating. When you put it closer to the disc, the atomic interaction between the disc and the needle changes the vibration frequency of the needle. By interpreting this change, a computer can read the topography of the disc," Chou explains. An actual player, which would probably employ voice-recognition software in its operating system, still needs to be built.

CDs can currently hold 10 minutes of high-quality video. DVDs hold 133 minutes per side, and Chou's penny-sized CD could hold 5 hours worth of video.—*Christopher Miller*

VIDEO

Window Views of Subway TV

IF YOU'VE EVER stared out a subway window wishing for something better than a tunnel wall to look at, then your dreams may be about to come true—in a way that recalls the old maxim about being careful of what you wish for.

As they travel from one station to the next, passengers on European trains will soon be watching short commercials projected onto a row of screens mounted on the walls of subway tunnels. Long lines of projectors, each showing a single frame at eye level, will be fitted along the tunnel. As the train passes, the impression of movement is created. A train traveling at a speed of 45 mph through a 600-yard tunnel could show a 30-second commercial or video clip.

The system reverses the projection techniques of cinemas, where the pictures move but the viewers sit still. The new system is highly sophisticated: Sensors adjust the number of images you see, according to the speed of the train. A stroboscope in each projector switches the images on or off at a rate governed by the train's speed and the spacing of its windows. Sound, however, may not be perfectly synchronized, because of the complex acoustics involved with matching sound to individual frames.

This summer, the German-built system will undergo trials in tunnels in Paris between the Quai d'Orsay and Invalides metro stops and in Berlin between the Zoologischer Garten and Hansaplatz stations. The German inventors of the system, MetroCinevision, already have plans for longer video presentations. "In the Channel Tunnel or Alpine tunnels, passengers could watch films up to 20 minutes long," notes Jorg Moser-Metius, a MetroCinevision film director.—*Marcus Gibson*

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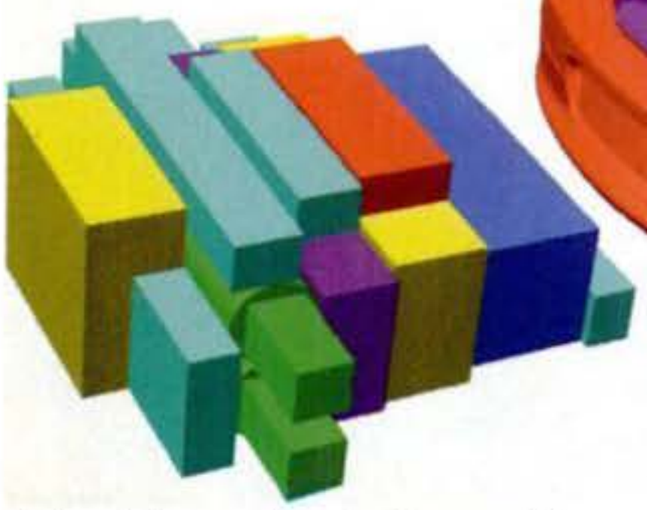
The all-new Dodge Intrepid is sleeker, smoother and even slightly lower than the first



Intrepid, so where in the world did we find more useable space? Why, in cyberspace of course. Despite the new Intrepid's slip-perier shape, our proprietary design and assembly software enabled a slight increase in cabin space and a considerable increase in trunk space. And that's in comparison to an automobile acclaimed for its spaciousness. By adding a folding 60/40 split backseat on Intrepid ES, we were able to accommodate pass-through storage for long items, making that useable space more use-able. We even found enough space to give Intrepid a larger glove box.

Of course more space wasn't all we found in cyberspace. The new Intrepid seats provide enhanced lateral and lumbar support with increased comfort. The ergonomically correct instrument panel is as sleek as the exterior, with integrated center console and soft-touch surfaces. The horn, of course, is right in the center of the steering wheel, where it belongs. Even our most powerful computers couldn't find a better location than that.

Cybe

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Intrepid The New Dodge

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r space.

Always use seat belts. Remember a backseat is the safest place for children.

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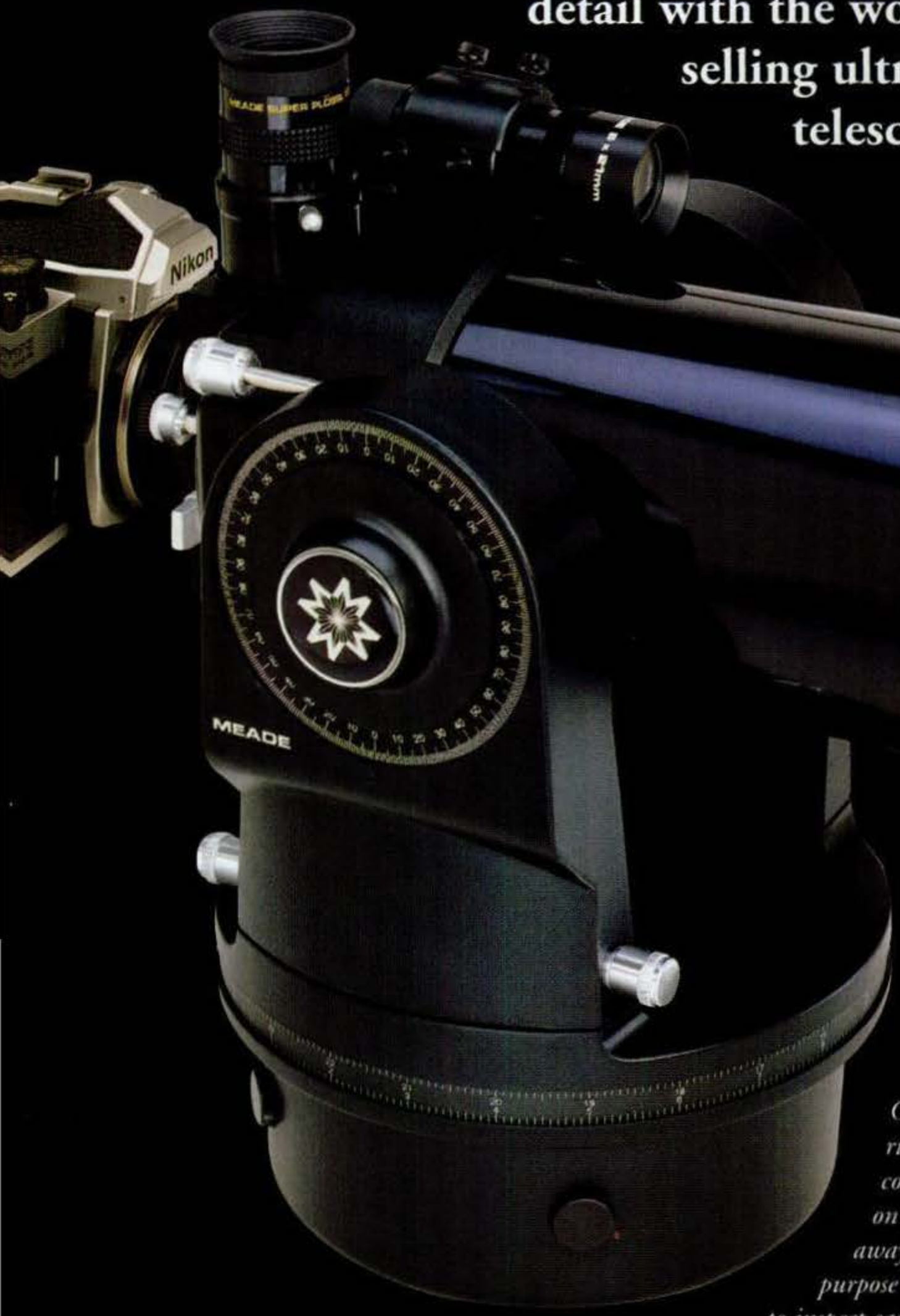
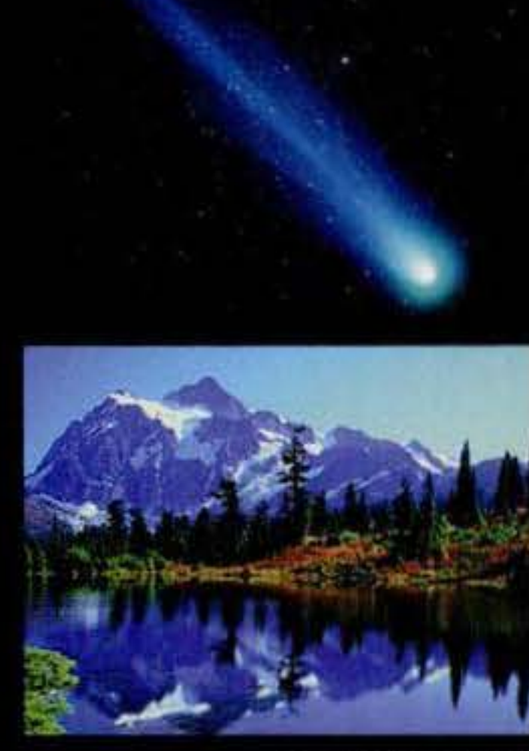


Explore hidden corners of the universe with the Meade ETX. As *Sky & Telescope* reported, "*The Cassini Division in Saturn's rings popped into view…I could see every wisp of velvet on the antlers of a deer 50 feet away…the ETX [is] an ideal all-purpose telescope for anyone wanting to inspect eagles at 100 yards or stars at 100 light-years…a compact, portable telescope with first-class optics.*" The Meade ETX: there's no other telescope like it in the world.



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BATTERIES

Longer Life via Fuel Cells

LONGER-LASTING batteries may be on the horizon, thanks to the development of a new power source for cellular phones, portable computers, and other portable electronic devices. The batteries, which are basically fuel cells, reportedly last up to 50 times as long as standard nickel-cadmium batteries.

Following a longtime dream of electrochemists to create electric power from hydrocarbon fuel, Los Alamos National Laboratory physicist Bob Hockaday has engineered a new miniature methanol fuel cell in his basement lab. Financial backing has been arranged to develop a manufacturing prototype. The battery, similar in size and price but half the weight of conventional batteries, is expected to have a major impact on the $1-billion-a-year cellular phone battery market. The product could be on store shelves by the end of next year.

Fuel cells work by converting the chemical energy from the oxidation of a fuel such as methanol directly into electricity. Hockaday's methanol fuel cell runs at room temperature like other batteries and will produce power at levels needed to operate a cellular phone—three-tenths of a watt in standby mode and 4 watts for conversation.

The micro-methanol cell is expected to last at least 20 years, whereas most contemporary batteries wear out after two.

Refueling the micro-methanol cell is as rapid and simple as pouring in 1.5 ounces of inexpensive methanol, instead of waiting several hours for recharging.—*Douglas Page*

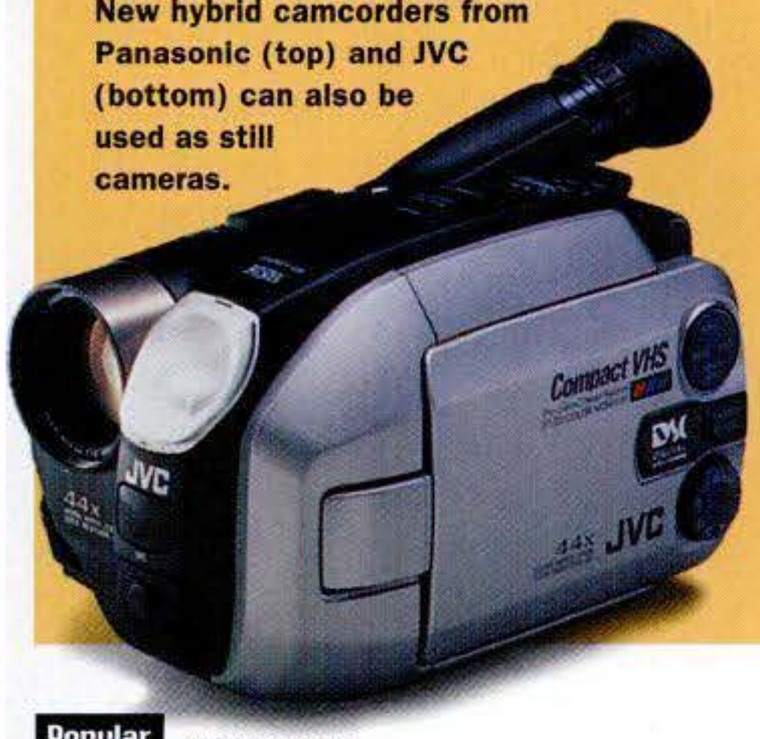
CAMCORDERS

Now with Stills

IF YOU'RE TIRED of carrying both a camcorder and camera to record moving and still images, then a new crop of hybrid camcorders may be to your liking. Camcorders such as JVC's GR-AXM700 ($1,000) and Panasonic's PV-L858 ($1,000) and PV-L958 ($1,100) models are hybrids: They incorporate a digital still camera. The digital equivalent of a roll of film can be stored in a separate electronic memory, but individual pictures can be easily inserted on the videotape. You can also view the still images on the camcorder's pop-out LCD screen.

Besides convenience, another advantage offered by these hybrid camcorders is the ability to use the camcorder's more powerful zoom lens while taking still pictures. Panasonic offers a 23X optical zoom lens that can be boosted digitally to 300X, while stand-alone digital still cameras may offer as little as 3X. Digital still photography has been an option in high-priced digital camcorders, but only now has this feature become available in lower-priced analog camcorders.—*F.V.*

New hybrid camcorders from Panasonic (top) and JVC (bottom) can also be used as still cameras.



What's changed about the car that changed everything?

If you know, you could win a Motorola StarTac Cellular Telephone courtesy of Popular Science

Tell us what's changed on the new Dodge Intrepid, and we'll enter you in the Intrepid I.Q. Sweepstakes. You'll find the answers in the Intrepid ad in this issue.

1. Where did we find more useable space?

a) In a broom closet.
b) Under the front passenger's seat.
c) In Cyberspace.
d) Next door.

2. Our proprietary design and assembly software enabled ...

a) An increase in the GNP of underdeveloped countries.
b) A slight increase in cabin space and a considerable increase in trunk space.
c) Better segmentation of various market sectors.
d) An outstanding balance of whiteners and fluoride treatment.

3. What do the new Intrepid seats provide?

a) A handy place to store used chewing gum.
b) Enhanced lateral and lumbar support with increased comfort.
c) A touch of Far Eastern artistry.
d) A lovely serenade.

4. What are two ways to get more information about Intrepid and The New Dodge?

Call 1-800 _____

or visit the Web site at www. _____

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Address _____

City _____ State _____ ZIP _____

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HOME TECHNOLOGY

EDITED BY WILLIAM G. PHILLIPS

AIR CONDITIONING

Evaporative Cooling Grows Up

EVAPORATIVE COOLERS, affectionately known as "swamp" coolers, have been popular for years because they're energy efficient and use no ozone-harming chlorofluorocarbons, or CFCs. Using the process of evaporation, the same principle that cools our bodies, swamp coolers pass air through wet pads to cool it. The downside: The air picks up humidity in the process.

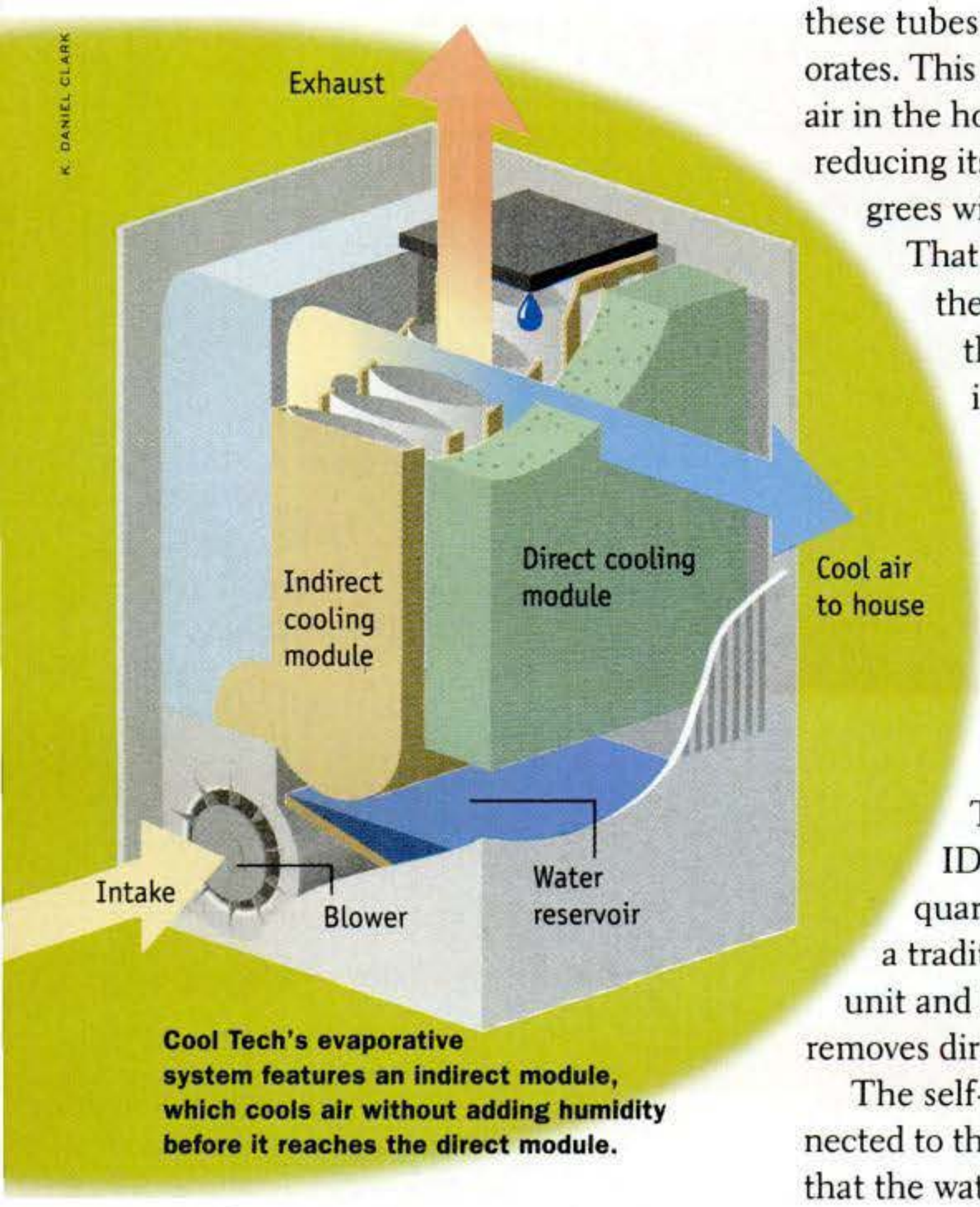
Cool Tech of Fair Oaks, California, may have solved the humidity problem. Instead of one cooling mechanism, the company's indirect evaporative cooler (IDEC) features two: direct and indirect cooling modules.

The indirect module is designed to cool air without adding humidity before the air arrives at the direct module. The inside of the indirect module consists of a series of air pathways—53 in all—perpendicular to one another and each sharing thin plastic walls with those beside it. Water pumped from an integrated reservoir slowly dribbles down the vertical tubes, and exterior air streaming up these tubes cools as the water evaporates. This draws heat away from the air in the horizontal passageways, reducing its temperature by 20 degrees without adding moisture. That air then moves through the direct unit—cooling further by 20 degrees—and into the house.

With this method of precooling, the humidity that finally reaches the home is at a comfortable level—it typically ranges between 50 and 70 percent, says Dan Field, president of Cool Tech. In addition, the IDEC consumes only one-quarter the energy of a traditional air-conditioning unit and features a purifier that removes dirt, pollen, and spores.

The self-purging reservoir, connected to the cold water line, ensures that the water does not accumulate bacteria—the source of the "swamp" smell associated with evaporative coolers. "The machine is continuously drawing new water as the coolant," Field explains, adding that the old water is piped outdoors.

One caveat: The IDEC cooler works only in areas that have low relative humidity, making it good for the West and Southwest U.S., but not feasible for most other areas. The unit costs about $3,900, including installation.—*Christopher Miller*



Cool Tech's evaporative system features an indirect module, which cools air without adding humidity before it reaches the direct module.

PEST CONTROL

Termite Tablets

UNIVERSITY OF Colorado entomologist Louis Bjostad and his colleagues have found that termites' natural reliance on carbon dioxide to find food and shelter can also be used against the insects as an alternative to current forms of pest control.

Bjostad, along with researchers Elisa Bernklau and Erich Fromm, made the discovery by placing two species of termites at one end of a T-shaped tube. In one arm, the researchers pumped in normal air; in the other arm, they pumped in carbon dioxide in concentrations higher than those found in normal soil.

When termites came to the point of choosing an arm, Bjostad says, most chose the side containing the carbon dioxide. He and his colleagues believe termites are naturally attracted to carbon dioxide for two reasons. Rotting wood, the termites' main food source, releases the gas, a process that likely guides the insects to food. Also, concentrations of the gas inside termite colonies are higher than that of ambient air, suggesting termites also use carbon dioxide to find home.

The researchers are now developing nontoxic effervescent tablets that would slowly dissolve and release carbon dioxide underground to lure termites away from houses and other structures. Currently, two are on the drawing board: one composed of carbon-dioxide-producing sodium bicarbonate and citric, and the other a mixture of carbon-dioxide-producing microbes and a food source.

Bjostad envisions an inexpensive termite-luring system consisting of a 6- to 8-inch steel pipe buried vertically in the ground. Homeowners would drop in a pesticide to kill termites once the carbon-dioxide-producing effervescent tablet was in place.—*Joseph Baneth Allen*

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R & D

Fighting Firestorms

EVERY YEAR, in late summer and fall, television news programs run heartrending video of homeowners in California and other parched locales desperately trying to save their houses from an onrushing firestorm by spraying their homes down with water. Sometimes their efforts succeed; but often, the water treatment is futile and the fire consumes the house.

Now researchers at the Fire Safety Division of the National Institute of Standards and Technology (NIST) believe that a better and less risky approach may be the preventive application of superabsorbent water-based foam sprays or gels to the exterior walls of houses.

In a recent NIST experiment, researchers built two wooden L-shaped frame walls and covered both with exterior vinyl siding. One hour before their test, they applied a moderate coating of a protein-based compressed air foam—which was developed from fish and horse parts and used for years to cover landfills—to one corner of one wall. The other wall's corner received no protective foam.

When the hour was up, both corners were exposed to a blast of flame with a power rating of 50 kilowatts for 10 minutes. Within 3 minutes of ignition, flames shot up into the eaves and roof area of the untreated corner. But the treated corner suffered only minor damage, with no spread of fire.

The next step, say the researchers, is testing the effectiveness of the agents in hot, dry, windy conditions typical in the western U.S.—*Arthur Fisher*

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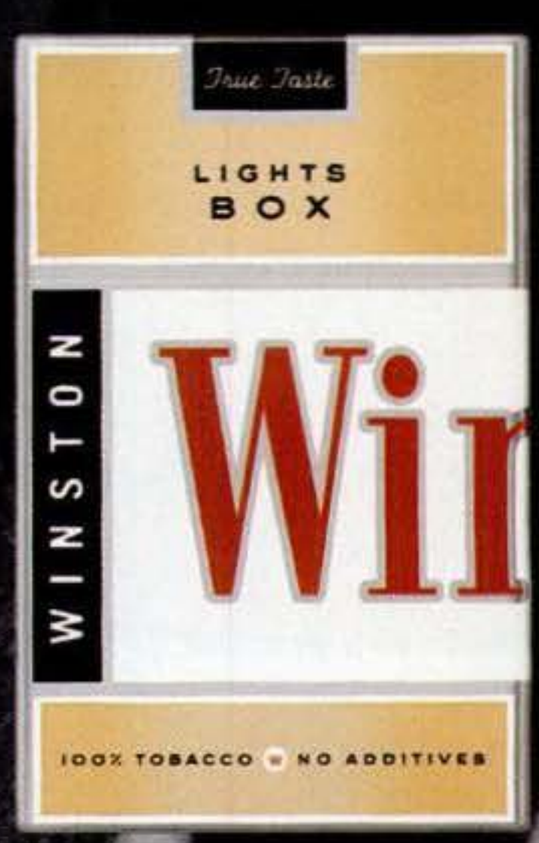

Copyrig

If it's going to last 15 years, make sure it's a color you can live with.

A paint color that looks perfect in the store may be less than perfect when you see it up on your house. Colors look different in different light. Here's a tip from the folks in the red vests, at Ace. When you feel that you've picked the right color, take home 3 or 4 chips of it and a few other colors that are close. Tape them to different locations on your house. In direct sunlight, in corners and under eaves. Look at them during the day, and again at twilight. Now you'll have a real good idea which color you'll want to live with for the next fifteen years or more.

COLOR SELECTION TIP

Your helpful hardware folks at ACE Hardware

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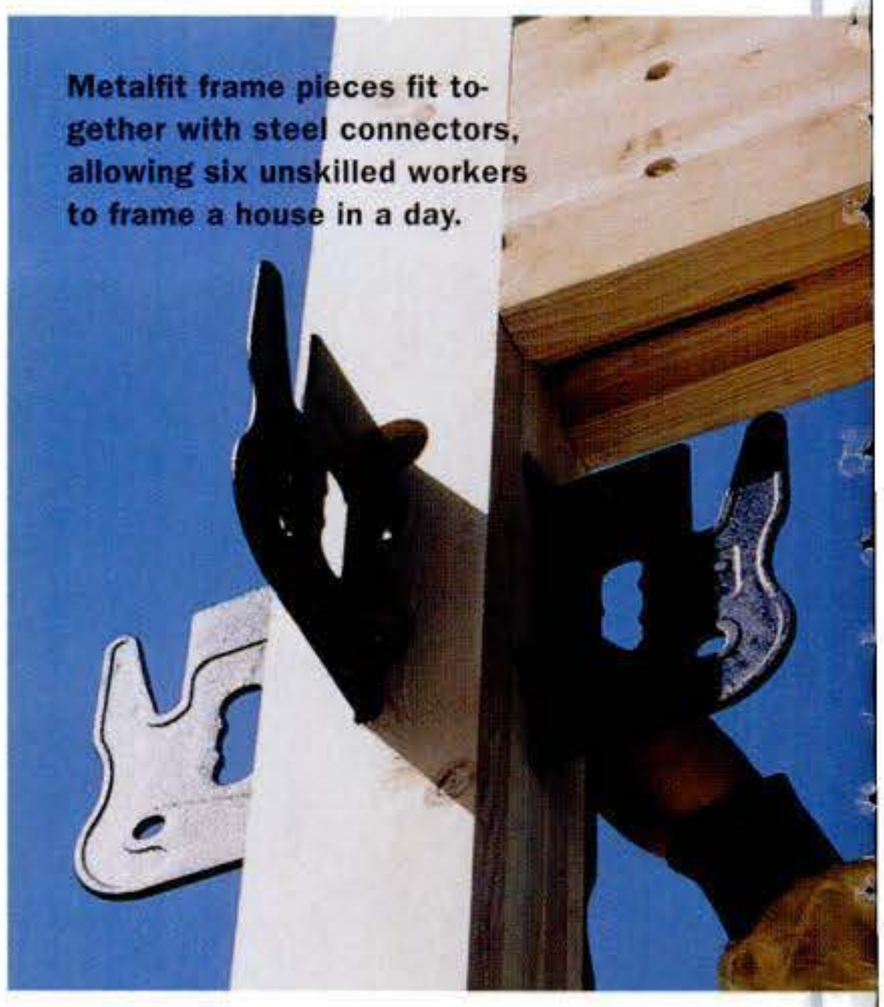
HOMEBUILDING

Fast Framing



Metalfit frame pieces fit together with steel connectors, allowing six unskilled workers to frame a house in a day.

ONE OF THE biggest crowd-pleasers at this year's International Homebuilders Show in Dallas was a prefabricated building system that enables six workers—no matter their skill level—to frame a house in a day. Developed by Kato Sangyo Ltd. of Shimane, Japan, the Metalfit framing system was designed to help meet rising housing demand in a country with a severe shortage of skilled labor. Now Metalfit is coming to the United States.

The system is built around a series of steel connectors that easily link the members of a post-and-beam house frame. But the frame isn't ordinary lumber. Atomu Yoshimura, Kato Sangyo's managing director, emphasizes that the steel connectors require a precisely milled frame that won't warp or twist. For that reason, Metalfit is made entirely of engineered wood—that is, wood from small trees and waste lumber that is compressed and then glued together to form larger, stronger pieces. Wall sheathing consists of engineered panels laminated to rigid-foam insulation. The panels are covered with housewrap.

Kato Sangyo's manufacturing process is equally as precise as its product. Blueprints are entered in the company's computer, which in turn commands an automated factory. The factory can cut the frame for a 1,600-square-foot custom-designed house in a day; it can crank out frames for identical tract houses at a rate of one per hour.

The system has certainly caught on in Japan. Yoshimura says that output grew from 200 houses three years ago to 2,000 last year. The company plans to open a U.S. factory soon. Once it does, framing a small house could become a weekend project within reach of nearly anyone.—*Charles Wardell*

RATINGS

Window Shopping Made Easy

BUYING WINDOWS has gotten a lot easier since the National Fenestration Rating Council (NFRC) began its testing and labeling program in the early 1990s. But while the ratings reliably compare the performance of new windows, they don't tell you how those windows will perform over time.

That's about to change. NFRC recently developed an aggressive testing protocol designed to evaluate long-term window degradation. The tests consist of an accelerated aging program that subjects the windows to high and low temperatures, rain, ultraviolet light, and thousands of openings and closings. The results of the tests will be used to adjust current window ratings.

Exactly what the adjusted ratings will look like isn't yet certain, but according to NFRC's Carl Wagus, they will probably include numbers that gauge the window performance when new and over time. "The consumer will get a more conservative rating," he predicts.—*C.W.*

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Popular Science

SPECIAL ISSUE

The International Space Station

BY NOW, SPACE SHUTTLE FLIGHTS have become so routine that they rarely make headlines. But when the shuttle Endeavour blasts into orbit in July, people all over the world will be watching, because Endeavour will be carrying two American construction workers into space. Equipped with the spacegoing equivalent of hard hats, cordless drills, and lunch boxes, astronauts Jim Newman and Jerry Ross will bolt together the first two pieces of the International Space Station. By the time the station is completed, around the end of 2003, it will be the size of a city block and one of the brightest objects in the night sky. Like the building of the pyramids, construction of the station will require years of heavy lifting and thousands of laborers. The work, shared by 16 nations, will be dangerous and expensive. But it will also be a grand adventure, one that is just as likely to produce unanticipated discoveries as it is to encounter unexpected challenges. To give you an advance look at what will be the largest peacetime engineering project in history, we devote this issue to the International Space Station.

Edited By Dawn Stover

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"To me . . .
every cubic inch of
space is a miracle."

—Walt Whitman, "*Miracles*"

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Centrifuge Accommodation Module

U.S. Lab

European Lab

Japanese Experiment Module

Habitation Module

Connecting node

Mini Pressurized Logistics Module

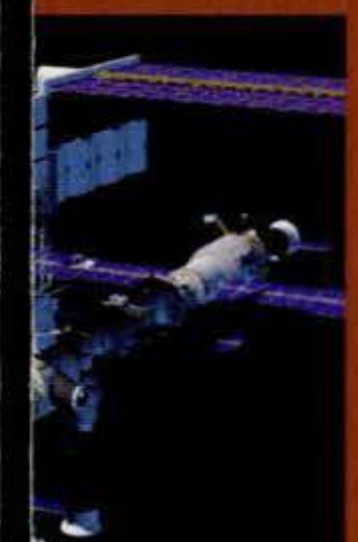
Canadian Remote Manipulator System

Remote Manipulator System (Canadian arm)
Special Purpose Dexterous Manipulator (Canadian hand)
Base System (work platform and storage area)

Robots Lend a Hand

Mechanical arms will be the workhorses of the station

MUCH OF THE ASSEMBLY WORK WILL BE DONE with the help of several different kinds of robotic arms. The largest is the 58-foot-long Remote Manipulator System contributed by Canada. This arm moves along rails on the truss work, and can also "walk" from place to place by attaching its free end to a grapple fixture and then releasing the other end. The arm can pick up and use a dexterous hand, which has two arms of its own, for precision tasks.



2001

By this time, the station will have more power from additional solar arrays. The Japanese Experiment Module will also have been delivered and activated.

2003

The ISS should be complete by 2003. Latest additions: Russian and European labs, more solar arrays, and a Habitation Module for the six-person crew.

check out these Web sites: station.nasa.gov, www.boeing.com

SOURCES: BOEING, NASA, SPAR AEROSPACE
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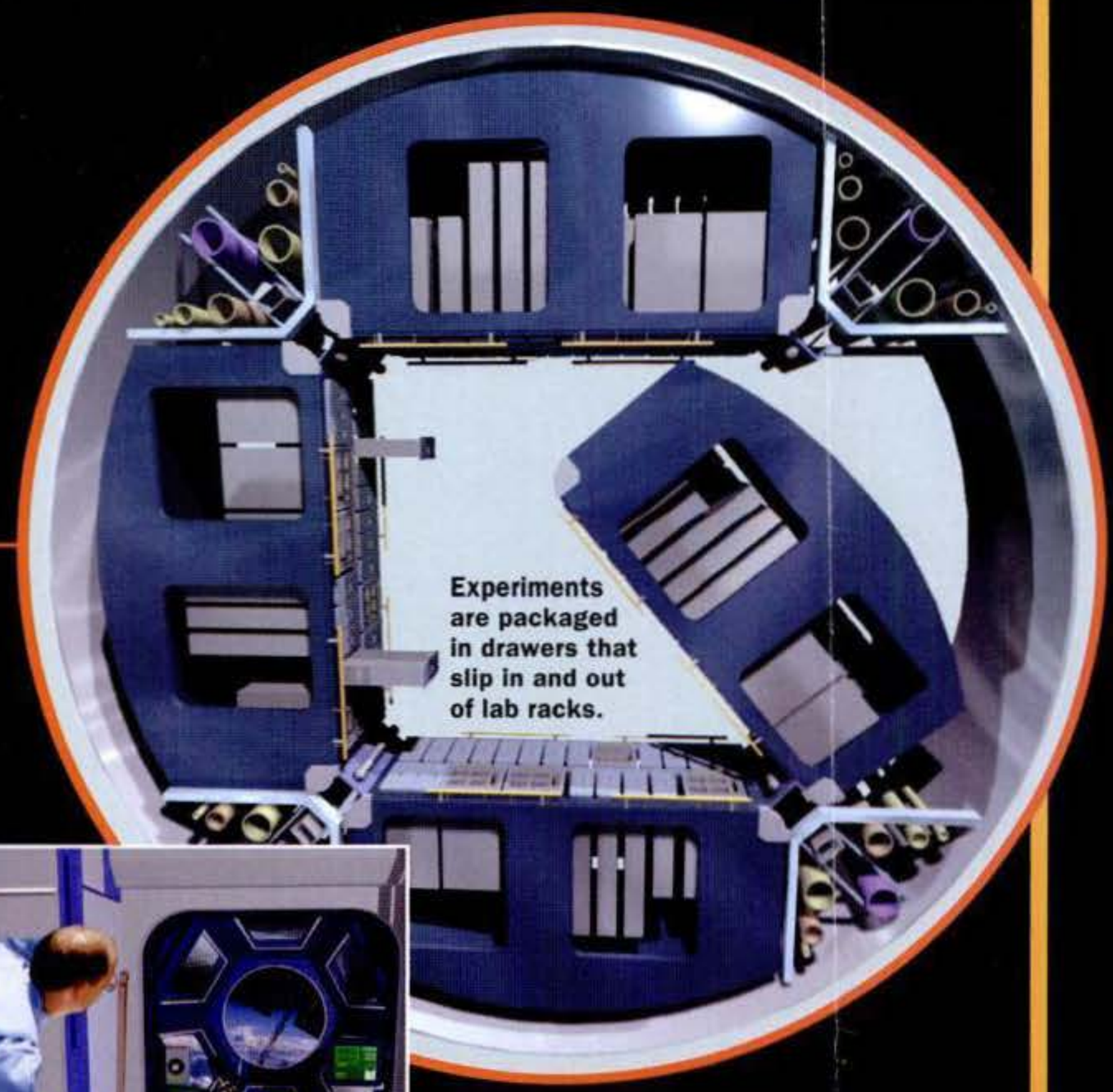
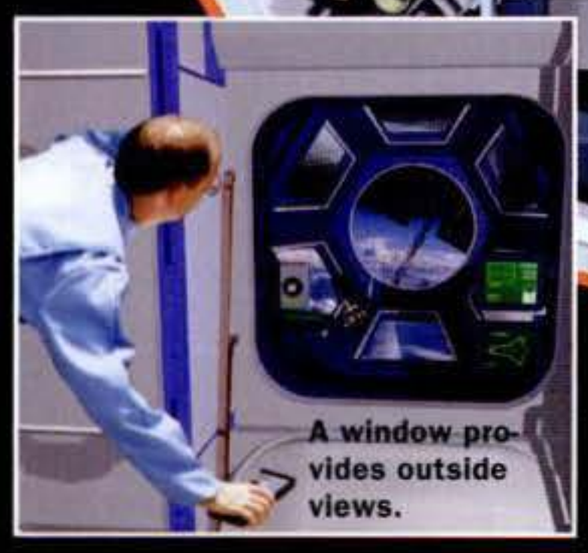
A Walk in the Dark

The tools and techniques of spacewalking missions

BUILDING THE STATION WILL REQUIRE more hours of extra-vehicular activities (EVAs), or spacewalks, than have been done in the past 35 years. During these EVAs, the astronauts will connect umbilicals that carry fluids and electricity between different parts of the station. Tethers and foot restraints will hold the astronauts in place while they work with special tools, sometimes in frigid darkness and sometimes in scorching sunlight. Backpacks regulate the temperature of the astronauts' suits and feature a built-in propulsion system in case of emergency.

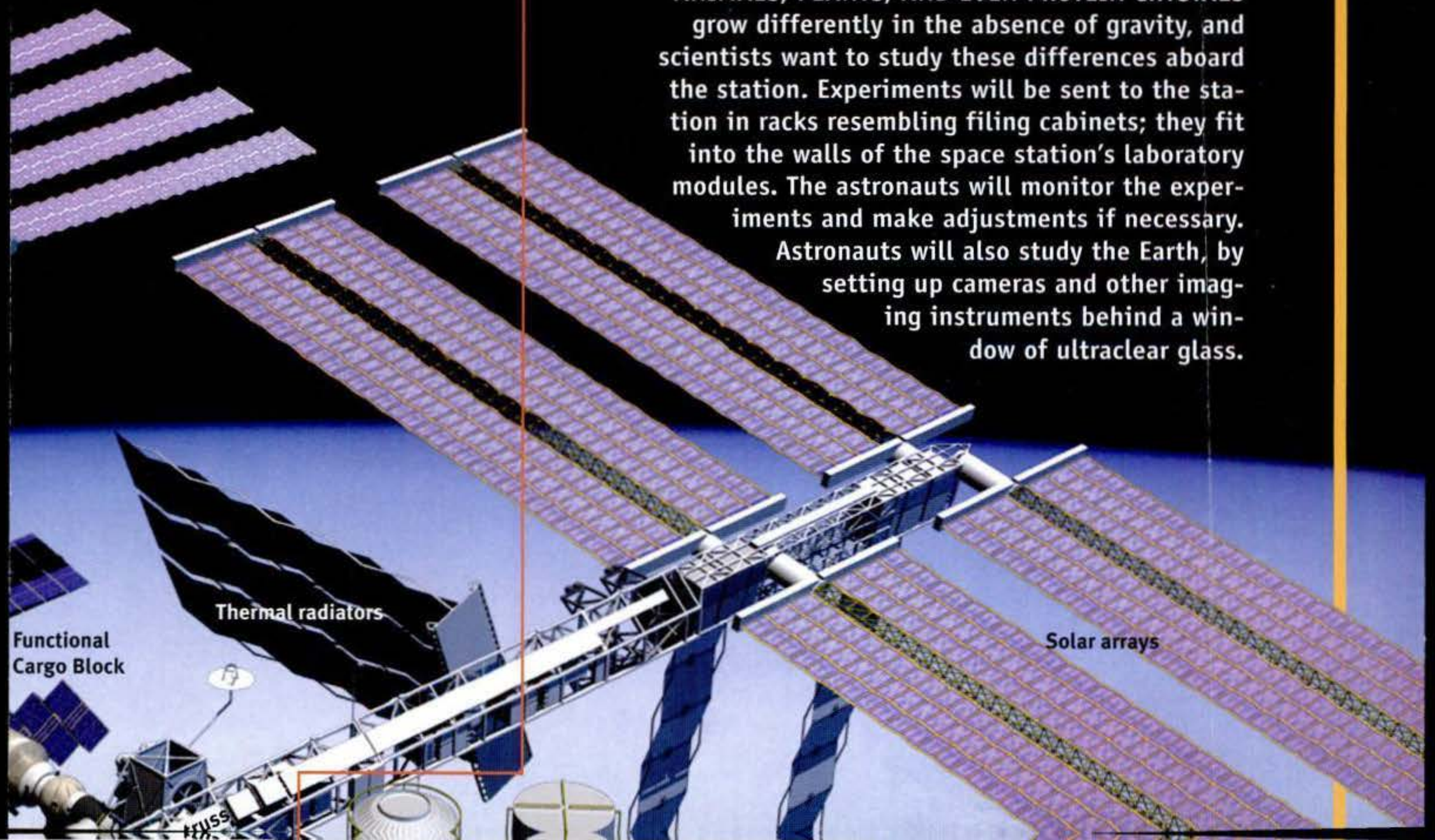


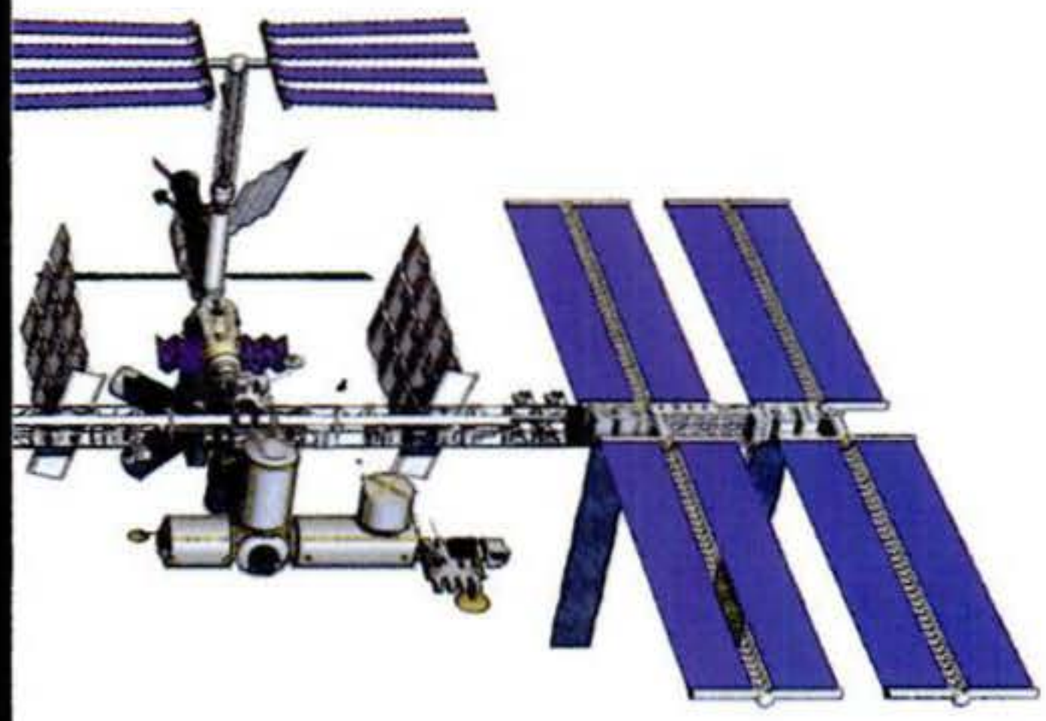


Station Science

Experiments will be conducted inside and outside the station

ANIMALS, PLANTS, AND EVEN PROTEIN CRYSTALS grow differently in the absence of gravity, and scientists want to study these differences aboard the station. Experiments will be sent to the station in racks resembling filing cabinets; they fit into the walls of the space station's laboratory modules. The astronauts will monitor the experiments and make adjustments if necessary. Astronauts will also study the Earth, by setting up cameras and other imaging instruments behind a window of ultraclear glass.





ISS: 356 x 290 feet

BOEING 747: 212 x 232 feet

SKYLAB: 84 x 22 feet

ROOM TO MOVE: The station will have 46,200 cubic feet of working space inside, equivalent to the volume of two Boeing 747s. Skylab, launched in 1973, had a volume of 9,700 cubic feet.

- Estimated number of Pepperidge Farm cookies that will be consumed on the space station per year: **800.**
- Number of times per week astronauts will change exterior clothing: **1.** Soiled suits are collected and jettisoned with the rest of the trash on the Russian Progress resupply craft.
- Weight of a space suit on Earth in pounds: **300.**
- Microgravity, the only gravity on the space station, is **1-millionth** of the gravitational force felt on Earth. A coin on Earth would fall 6 feet in 0.5 seconds. On the station, it would take 10 minutes.

'ROUND THE WORLD

220 miles
Average altitude of the station

17,500 miles per hour
Station's speed in orbit

90 minutes
Time it takes for the station to orbit Earth

85 percent
Amount of Earth seen from the station during its orbit

AN INTERNATIONAL AFFAIR

The space station is the largest international peacetime project in history, with 16 countries participating. They include the United States, Russia, Canada, Japan, Brazil, and 11 European nations. Russia and the United States will contribute separate sections. Japan and Europe will add lab and research facilities.

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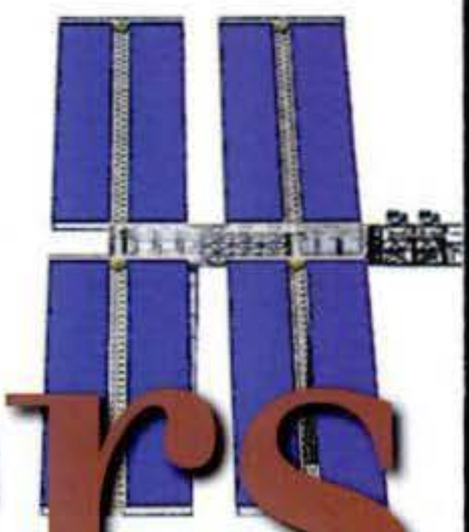
ISS by the Numbers



The first statistics are simple: 1 International Space Station, 3 original crew members, 16 contributing countries. But a further sampling hints at the magnitude of the mission and gives us a window into the life of an ISS astronaut.

STATION STATS

- **$29.4 billion** Total official estimated cost for the International Space Station.
- **$9** Cost to each U.S. citizen for the station's first year in space.
- **45** Launches of space shuttles and Russian boosters required to assemble more than 100 pieces.

- **1,100** Estimated hours of spacewalks required to complete the station—roughly **400** more than total spacewalking hours in the history of the U.S. space program.
- **1.04 million pounds** Weight of the space station. But when it falls back to Earth years from now, only about **100,000 pounds** will land in the ocean; the rest will burn up in the atmosphere.
- **-250°F to +250°F** Temperature range outside the space station.
- **1 acre** Amount of equivalent space the station's solar panels would take up.
- **2 football fields** Area covered by the space station—so big the station will be visible to the naked eye from Earth.
- **200 feet long** The swimming pool in which the astronauts train, located at the Johnson Space Center in Houston, is one of the largest in the world. It's **100 feet wide** and **40 feet deep**.

LIFE IN SPACE

- Number of people in space station's initial crew: **3**. When completed, the station will have a standard crew of **6** people, but can accommodate **7**.
- Time it takes the average person to adjust to life in space: **4 days**.
- Number of gallons of water an astronaut on the station will consume per day: **8**. The average American uses **160**. At least **85 percent** of the water in the astronauts' urine will be recycled.
- Among the favorite foods in space: shrimp cocktail, steak, whole cashews, lemonade.

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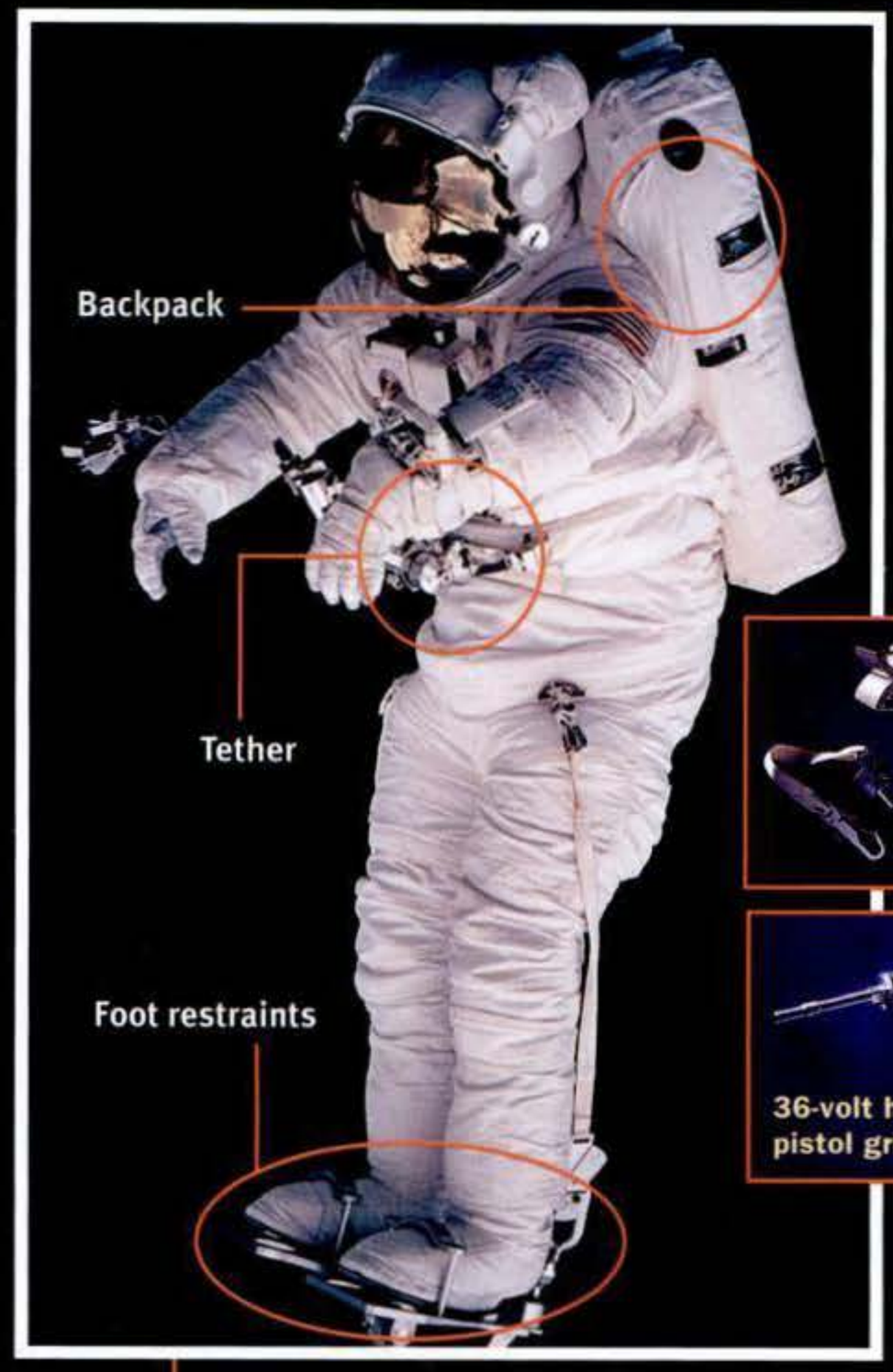
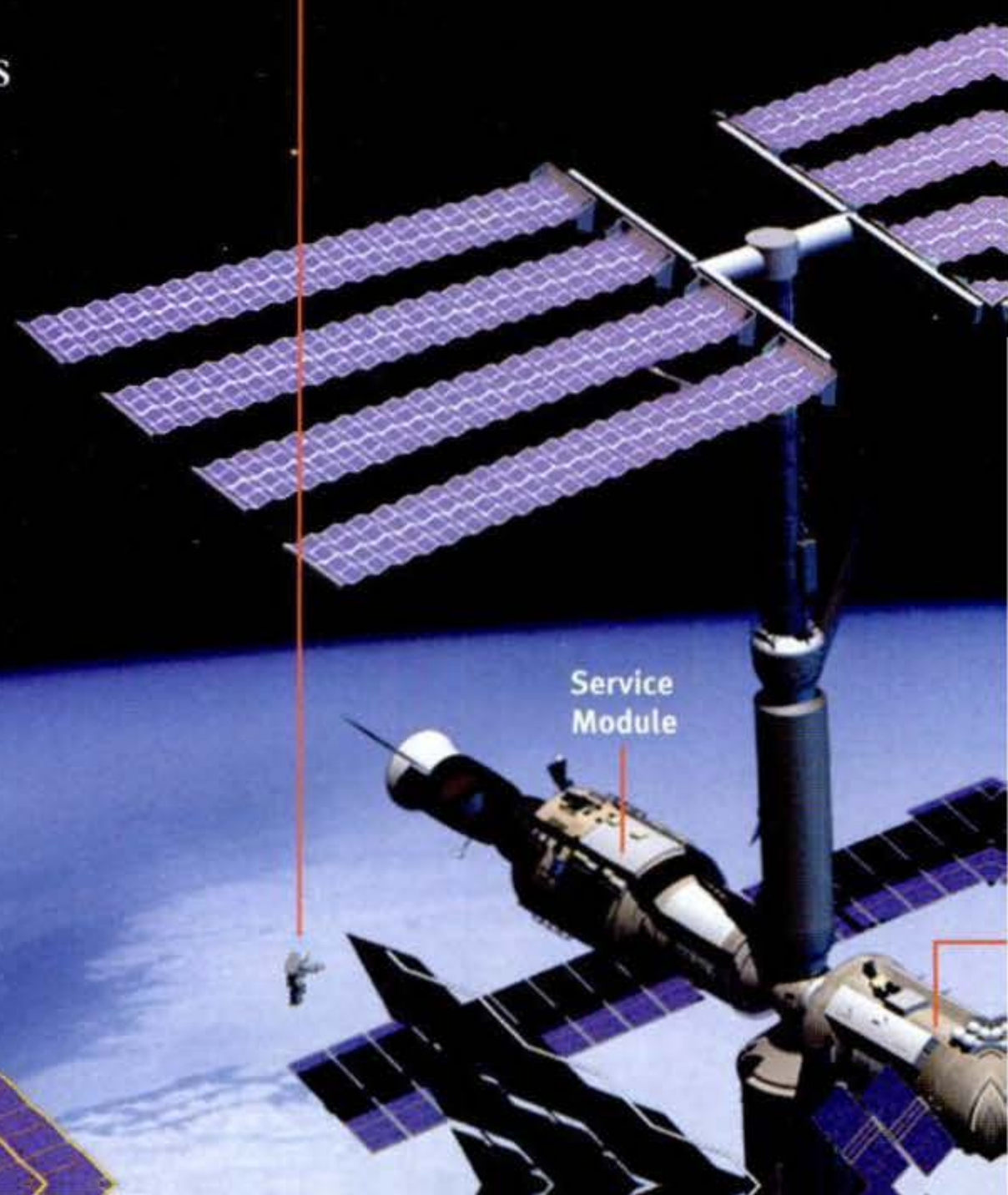
The International Space Station

IT WILL BE THE LARGEST, most complex structure that has ever been placed in orbit. When the International Space Station is completed in the year 2003, it will cover an area approximately the same size as two football fields and will sleep seven. Built by a partnership of 16 nations, the station will be a giant laboratory for learning how to live and work in space—in preparation for future manned trips to the moon, Mars, and the universe beyond.

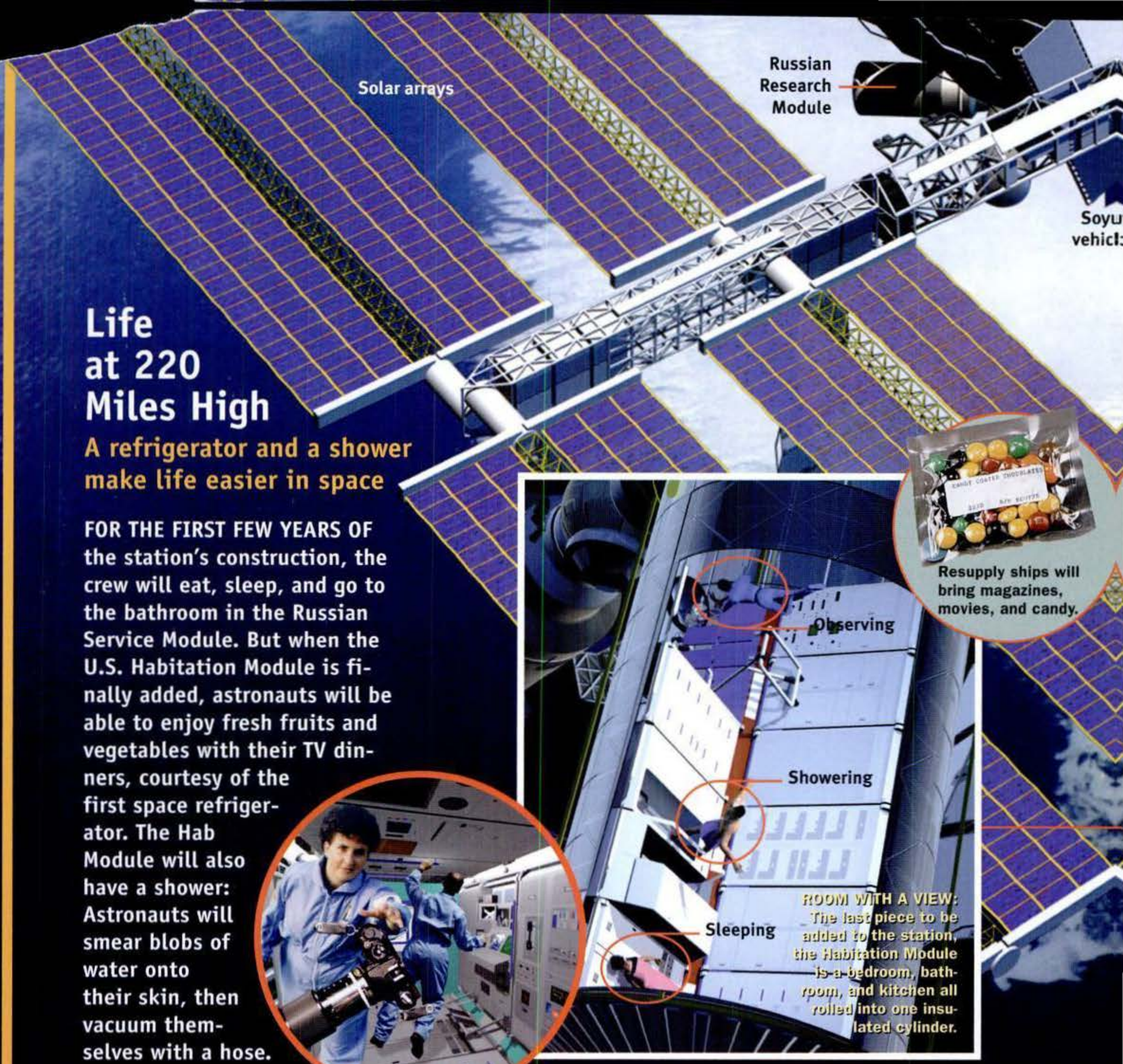




Life at 220 Miles High

A refrigerator and a shower make life easier in space

FOR THE FIRST FEW YEARS OF the station's construction, the crew will eat, sleep, and go to the bathroom in the Russian Service Module. But when the U.S. Habitation Module is finally added, astronauts will be able to enjoy fresh fruits and vegetables with their TV dinners, courtesy of the first space refrigerator. The Hab Module will also have a shower: Astronauts will smear blobs of water onto their skin, then vacuum themselves with a hose.



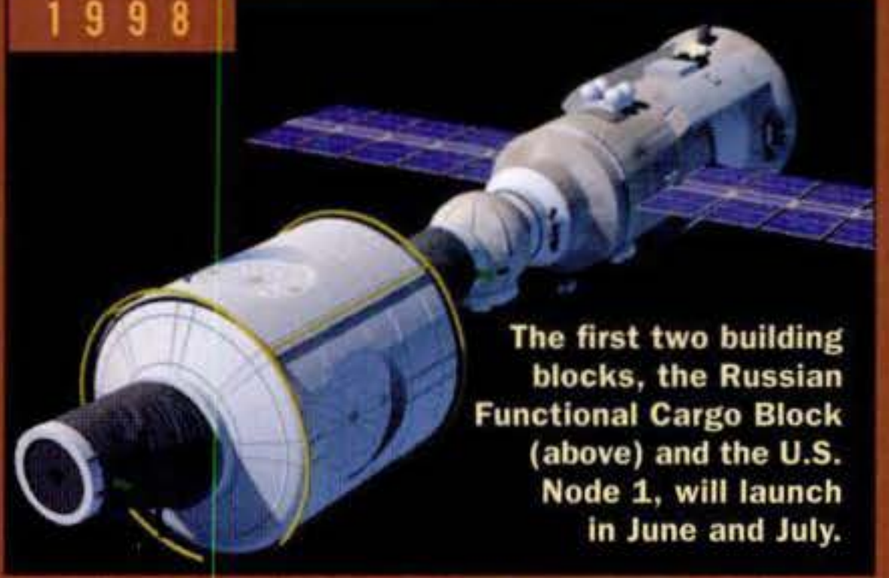
Resupply ships will bring magazines, movies, and candy.

ROOM WITH A VIEW: The last piece to be added to the station, the Habitation Module is a bedroom, bathroom, and kitchen all rolled into one insulated cylinder.

ASSEMBLY STAGES

ASSEMBLY WILL BEGIN THIS SUMMER, but it will take 45 launches of space shuttles and Russian boosters before the ISS is completed. With elements of the station coming from all around the world, many of the pieces will meet for the first time in orbit. Any problems with launch vehicles or individual elements could set back the whole schedule.

1998



The first two building blocks, the Russian Functional Cargo Block (above) and the U.S. Node 1, will launch in June and July.

1999

By summer's end, the station will have living quarters for a three-person crew, a functional laboratory module, a set of solar arrays, a pair of thermal radiators, and the Canadian robotic arm.

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For progress reports on the International Space Station,

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NASA

In a training pool, astronaut Jerry Ross rehearses assembly of the station's truss structure.

It's a strange way to build a house: one room at a time.

The Sum of Its Parts

By Jim Schefter

LATE JUNE IN KAZAKHSTAN. A RUSSIAN Proton rocket sits poised for launch at the once-secret Baikonur space base. Observers from NASA and other space agencies have crowded into the vintage control room, and journalists from around the world are monitoring the countdown. At zero, the Proton's engines thunder; it lifts away from Earth and quickly disappears from sight. The first module of the long-awaited International Space Station is headed for orbit.

If all goes well, that will be the scene just a month from now, when one of the world's most ambitious engineering projects finally gets off the ground. In January 1999, after six launches by U.S. space shuttles and Russian boosters, a three-man crew will take up residence. From that moment onward, the space station will be a permanent off-planet extension of human civilization.

When the station is completed, around the end of 2003 if NASA sticks to its schedule, it will be a multiroom hotel and research facility orbiting the Earth every 90 minutes. Its permanent population will be six or seven, with the mix shifting as Americans, Russians, Europeans, and Japanese move in and out over the months and years. By that time, resupply and assembly flights by shuttles or Russian rockets will have become so routine that today's breathtaking series of space rendezvous is certain to become tomorrow's humdrum.

You'll know the ISS is there. Five times the size of the Russian space station Mir, it will have solar wings and radiators sprouting from trusses spanning 356 feet. Its central core will be a collection of motor-home-size labs,

INFOGRAPHICS BY BOB SAULS/JOHN FRASSANITO & ASSOCIATES

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THE FIRST FLIGHTS

BY THE END OF THIS YEAR, if all goes as planned, two U.S. space shuttles and three Russian boosters will have launched the core modules of the International Space Station, making it habitable for a three-person crew.

FGB
June 1998
First to be launched, the FGB has solar panels that can fold inward to make room for later arrivals.

NODE 1
July 1998
The second piece in orbit, Node 1 serves as a passageway between Russian and U.S. elements.

The node has six attachment points, two on the ends and four on the sides.

living quarters, and supply canisters plugged together like a supersize Lego set. Together they'll fill a fore-to-aft length of 290 feet, almost as long as a football field.

The final configuration, requiring 45 separate space launches over at least six years and many long days of spacewalks by astronaut construction workers, will track diamond-bright across the night sky. Only the moon and Venus will be bigger and more visible.

"It takes a while to get perspective on how big this thing is," says Kevin Chilton, the station's operations manager at the Johnson Space Center in Houston. To demonstrate, he stretches his arms across a model of the station without reaching either end. The space shuttle docked to the station is only the size of a football and almost lost in the labyrinth of trusses, panels, and modules.

The station's complexity is as awesome as its size. Built by a partnership of 16 nations, ISS will consist of hundreds of individual elements that come from all over the world. "Most of the elements will never be physically mated until they come together in orbit," explains Randy Brinkley, NASA's Houston-based program manager for the space station. "But we're confident that when we turn on the lights, it will all work."

NASA is relying on Boeing, its prime contractor for the station, to ensure that all of the pieces fit together properly and work exactly as planned. Boeing has plenty of experience building complicated flying machines from parts made by far-flung suppliers: The company's 777 airliner, introduced four years ago, was designed and digitally preassembled on computers. "We're borrowing heavily from our brethren in Seattle on the 777 program," says Douglas Stone, Boeing's program manager for the space station.

But even if all the pieces fit perfectly, the assembly process itself will be risky. Unlike an airplane, the space station is flown while it's being built, and each new piece that is added may change the way the station behaves in flight.

Computer software problems are also a concern, "probably the biggest single risk that we face on this project," says Stone. Like the hardware elements, the software components come from all over the world and must mesh smoothly. The astronauts won't even be able to turn on the station's lights without help from a computer, because all of the electric power switching will be controlled by software.

Working hand in hand with other countries will be another challenge. "This station is really a new era for all of us," says Chilton. "We've had to learn how to be good guests on Mir and at the Russian training and command centers. Now we're going to be equal partners."

The station is divided roughly into two sections, one built primarily by the United States and the other built by Russia. "In some ways, it looks like two different spacecraft in close proximity," says Stone, "but to the crew, it will all be one vehicle."

The other nations participating in the project are also contributing hardware: Japan's space agency, NASDA, is supplying a laboratory module that includes a "back porch" where experiments can be exposed to space; astronauts will use a robotic arm to lift experiments onto the porch from an

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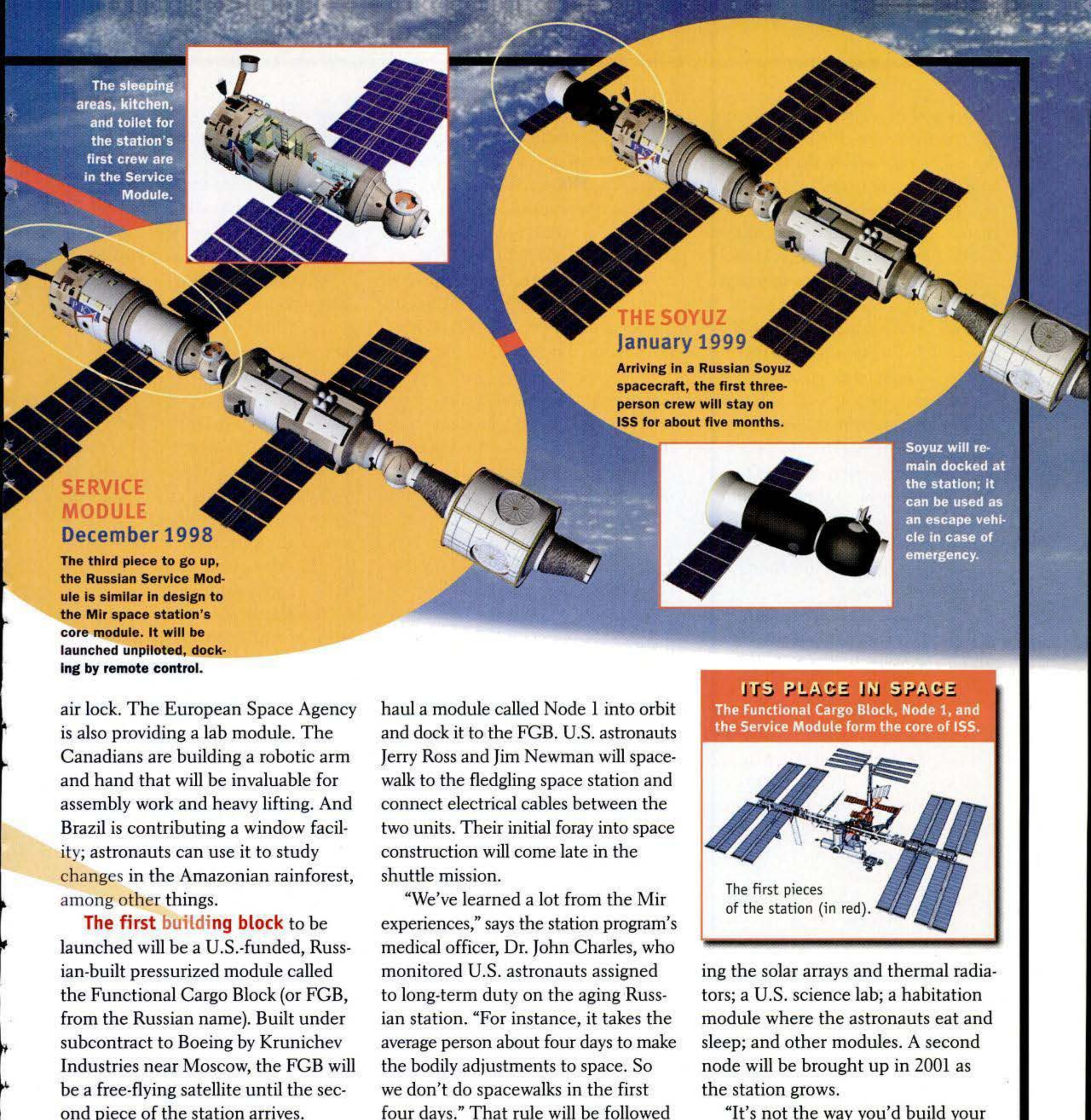
The sleeping areas, kitchen, and toilet for the station's first crew are in the Service Module.



THE SOYUZ
January 1999

Arriving in a Russian Soyuz spacecraft, the first three-person crew will stay on ISS for about five months.

Soyuz will remain docked at the station; it can be used as an escape vehicle in case of emergency.

SERVICE MODULE
December 1998

The third piece to go up, the Russian Service Module is similar in design to the Mir space station's core module. It will be launched unpiloted, docking by remote control.

air lock. The European Space Agency is also providing a lab module. The Canadians are building a robotic arm and hand that will be invaluable for assembly work and heavy lifting. And Brazil is contributing a window facility; astronauts can use it to study changes in the Amazonian rainforest, among other things.

The first building block to be launched will be a U.S.-funded, Russian-built pressurized module called the Functional Cargo Block (or FGB, from the Russian name). Built under subcontract to Boeing by Krunichev Industries near Moscow, the FGB will be a free-flying satellite until the second piece of the station arrives.

About the size of a long camper trailer, the FGB is a 20-ton multipurpose power and propulsion plant that gets the station assembly work started. A pair of solar panels will unfold in orbit to provide electrical power. The FGB carries propulsion and fuel storage—to keep the early station components in orbit—and docking ports at each end of its canister shape.

In July, the shuttle Endeavour will haul a module called Node 1 into orbit and dock it to the FGB. U.S. astronauts Jerry Ross and Jim Newman will spacewalk to the fledgling space station and connect electrical cables between the two units. Their initial foray into space construction will come late in the shuttle mission.

"We've learned a lot from the Mir experiences," says the station program's medical officer, Dr. John Charles, who monitored U.S. astronauts assigned to long-term duty on the aging Russian station. "For instance, it takes the average person about four days to make the bodily adjustments to space. So we don't do spacewalks in the first four days." That rule will be followed throughout space station construction.

Node 1, built by Boeing in Huntsville, Alabama, is a pressurized module with six ports. One mates with the FGB, and the opposite port will be the early connection between shuttles and the station. Other ports will eventually get docking units to which more modules will be attached.

As the assembly continues, the node will sprout the long main truss holding the solar arrays and thermal radiators; a U.S. science lab; a habitation module where the astronauts eat and sleep; and other modules. A second node will be brought up in 2001 as the station grows.

"It's not the way you'd build your house," says Brinkley. Most housebuilders would start by erecting an outer shell; finishing the individual rooms would come much later in the construction process. But to construct a space station, says Brinkley, "you build the bathroom, and live there at first." Then you add the other rooms, one module at a time.

When Endeavour leaves the mated FGB and the first node behind,

ITS PLACE IN SPACE

The Functional Cargo Block, Node 1, and the Service Module form the core of ISS.

The first pieces of the station (in red).

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the longest quiet period in the assembly process begins. It will be at least several months before the third station element, the Service Module, is sent up from Baikonur. Using automated docking procedures perfected by the Russians, the Service Module will mate to the FGB port opposite from Node 1.

The Service Module, which is based on technology used in the Mir station's core module, carries the environmental controls and life support system for the entire station. It also has the primary docking port for Russia's Soyuz spacecraft, and the fuel and rockets for both attitude control and station reboost. Reboost is needed periodically to raise the space station's orbit and keep it from reentering Earth's atmosphere.

The Service Module has been the most problematic component of the station, because the Russians have fallen behind schedule in building it. Last year, NASA became so concerned about the delivery of the Service Module that the agency negotiated a $170 million contract with the Navy to develop an alternative—by modifying a Navy spacecraft built in the early 1980s.

"It was a spinning upper stage to boost shuttle-launched Navy satellites into higher orbits," says Ed Senasack of the Naval Research Laboratory. The spacecraft was abandoned after the Pentagon canceled military use of the shuttle in the wake of the Challenger disaster, and was headed for the scrap heap. "It needed some modifications, but we saw immediately that it could fill in for the Russian Service Module," Senasack recalls.

For now, the Service Module seems to be on track. But the modified Navy hardware, renamed the Interim Control Module, is still under development. If the Russians falter again, the ICM will be ready for flight. If not, the ICM can provide additional storage and boosting capabilities for the space station.

Assuming the Service Module is delivered in time to be launched in December or early 1999, it will be docked to the first two pieces of the station. Its solar wings will then be deployed, doubling the electrical power capacity of the connected units.

Then the business of building a space station gets hectic. A total of 14 shuttle and Soyuz booster missions to the ISS are scheduled for 1999. In January, the shuttle Atlantis will haul up a variety of components to be plugged into Node 1's ports or to be installed inside. Among these are the first truss structure and a third docking port.

The docking port will later be used by a shuttle to offload the first large solar array provided by the United States. It will be attached to the truss in April 1999. Made by Lockheed Martin Missiles & Space, the solar panels are roughly 100 feet long, the largest ever built for space. A total of 16 panels will eventually be installed, covering about an acre.

While the U.S. solar arrays will provide the electrical power for life support and scientific experiments aboard the station, Russia will supply the propellant fuel to keep the structure in orbit. "We're the power company, and they're the gas company," explains Brinkley.

But long before all of the solar panels are installed, the ISS will open for business. "The crew will come up immediately," manning the station as soon as Atlantis delivers its load of critical hardware in early 1999, Brinkley says. Barring any major emergencies, the ISS will never again be without human occupants.

The station's first commander will be an American, Navy Captain and former SEAL Bill Shepherd. He and two Russians will ride into orbit aboard a Soyuz spacecraft, which will be docked to the station and serve as an emergency rescue vehicle. Future crews may ride up in a shuttle and come back in a Soyuz, or vice versa.

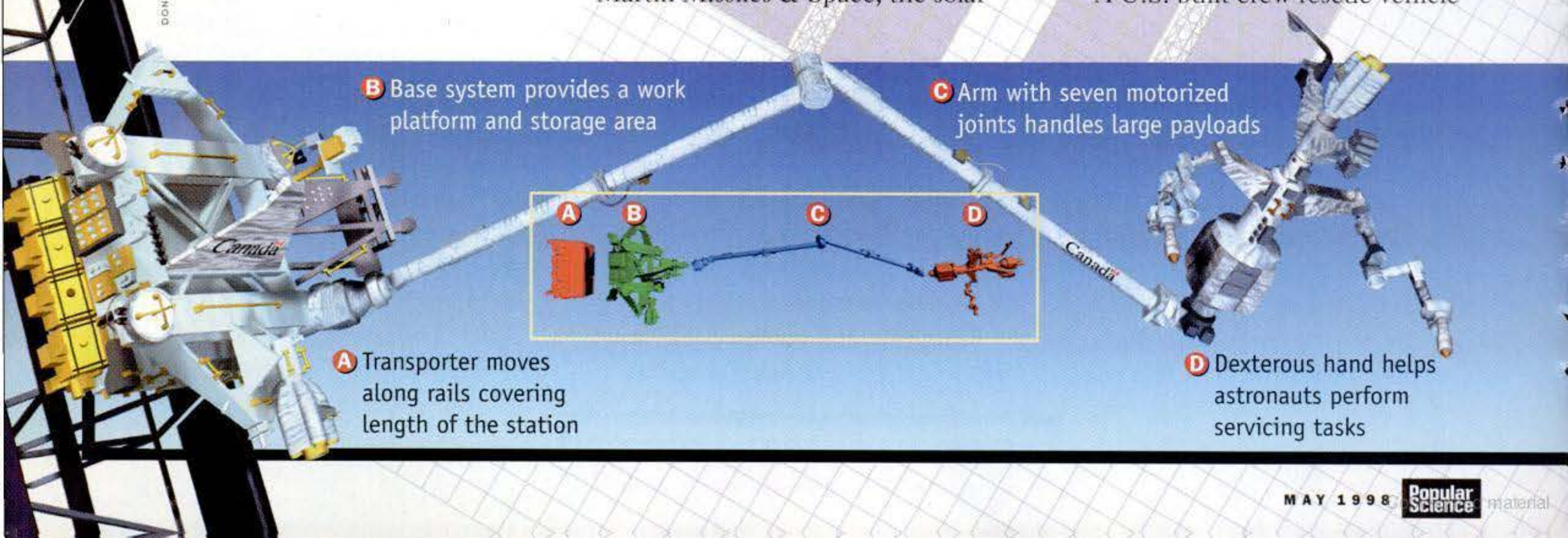
When the U.S. Laboratory Module is attached in mid-1999, the station will begin looking something like its artists' portraits. The first crew will leave a month later, and a team of one Russian and two Americans will take over, probably for a five-month stay. "We're still staying with our basic agreement with our Russian partners," says Chilton, "that during the assembly phase, we will share time on orbit fifty-fifty for the crews."

A U.S.-built crew-rescue vehicle

THE CANADIAN ARM

DESIGNED BY Spar Aerospace for the Canadian Space Agency, the Mobile Servicing System is a four-piece robotic tool that will play a key role in assembly and maintenance. Astronauts control it using computers inside the station.

DON FOLEY


B Base system provides a work platform and storage area
C Arm with seven motorized joints handles large payloads
A
B
C
D
Canada
Canada
A Transporter moves along rails covering length of the station
D Dexterous hand helps astronauts perform servicing tasks

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will be added to the station in 2003. After that, a six-person crew will occupy the station. Some astronauts may stay as long as 187 days, but there are no plans yet for longer missions. (The official life expectancy of the station itself is 10 years, but it should last much longer.)

"The Russians say that six months is the maximum-efficiency stay in space," Dr. Charles says, "but I think it could really be years. The key is exercise, and there's probably no time limit for a healthy person up there."

Dr. Al Holland oversees crew psychology at the Johnson Space Center. Working with the Russians and with other nations is bound to create some problems, he thinks. "The big challenges are going to be with the first few crews," he says, "and those will be organizational—setting up shop, solving hardware problems, talking to control centers in Moscow and Houston."

After that, life aboard the ISS should settle into a routine. Holland likens it to a naval deployment. "You're not going up there to drive something," he says. "You're going up to do a job. In the end, a space station is like a ship, not like a shuttle."

But these space sailors are building their own ship from scratch, in the middle of an unforgiving empty ocean. Getting from here to there is going to be a challenge. ◆

YOU ARE HERE

IT'S EASY TO GET LOST in this complex 3-D structure, so we created a blueprint to help you find your way around. Here are locations for the key components that you'll be reading about in the following pages of this special issue.

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WHERE THE SECRETS

TO THE UNIVERSE ARE KEPT.

The answers do not lie in technology. Technology is

but a stepping stone to the next question. We are fueled

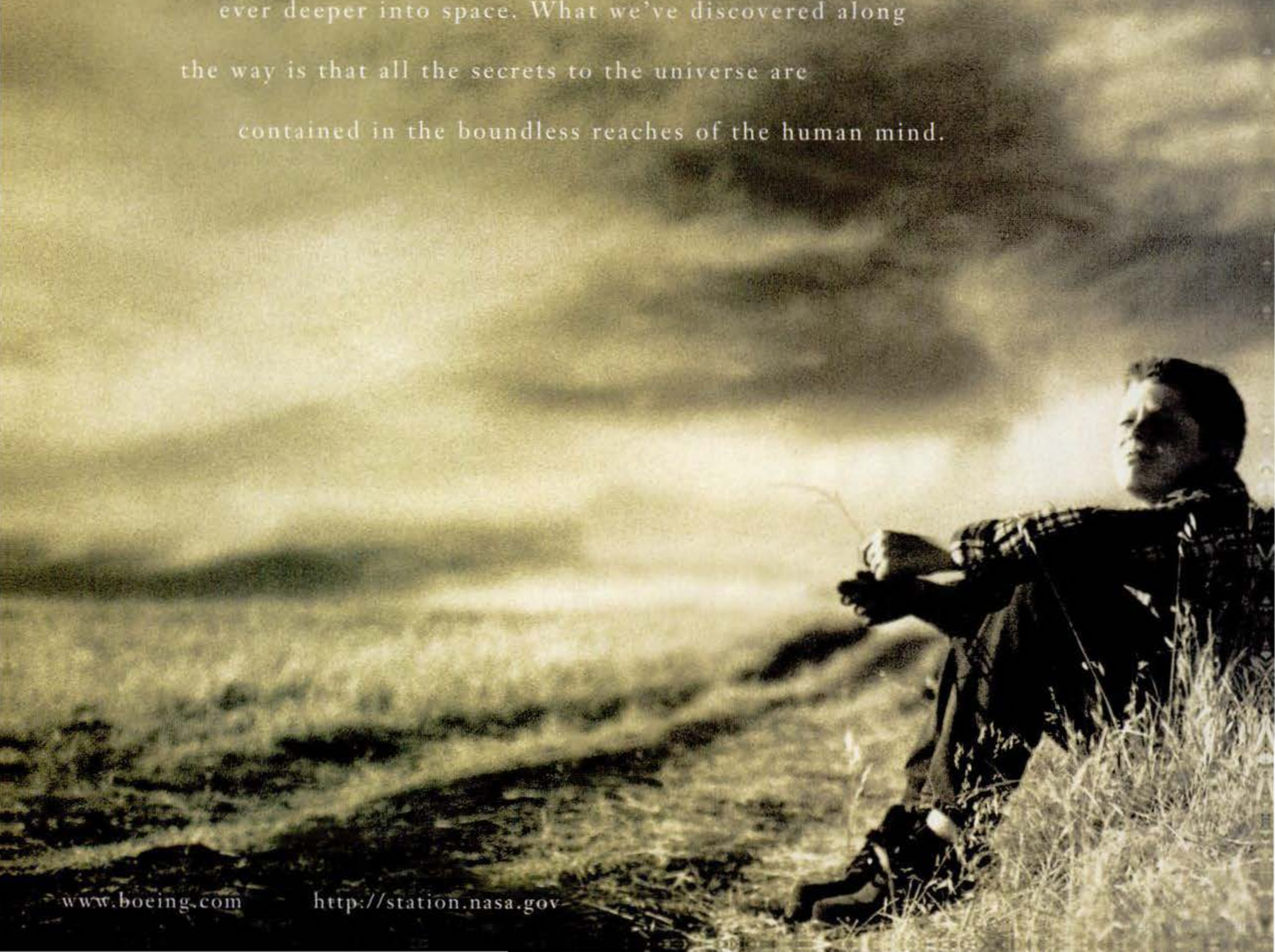
by a restless imagination; an endless sense of wonder

that has brought our world closer together and led us

ever deeper into space. What we've discovered along

the way is that all the secrets to the universe are

contained in the boundless reaches of the human mind.



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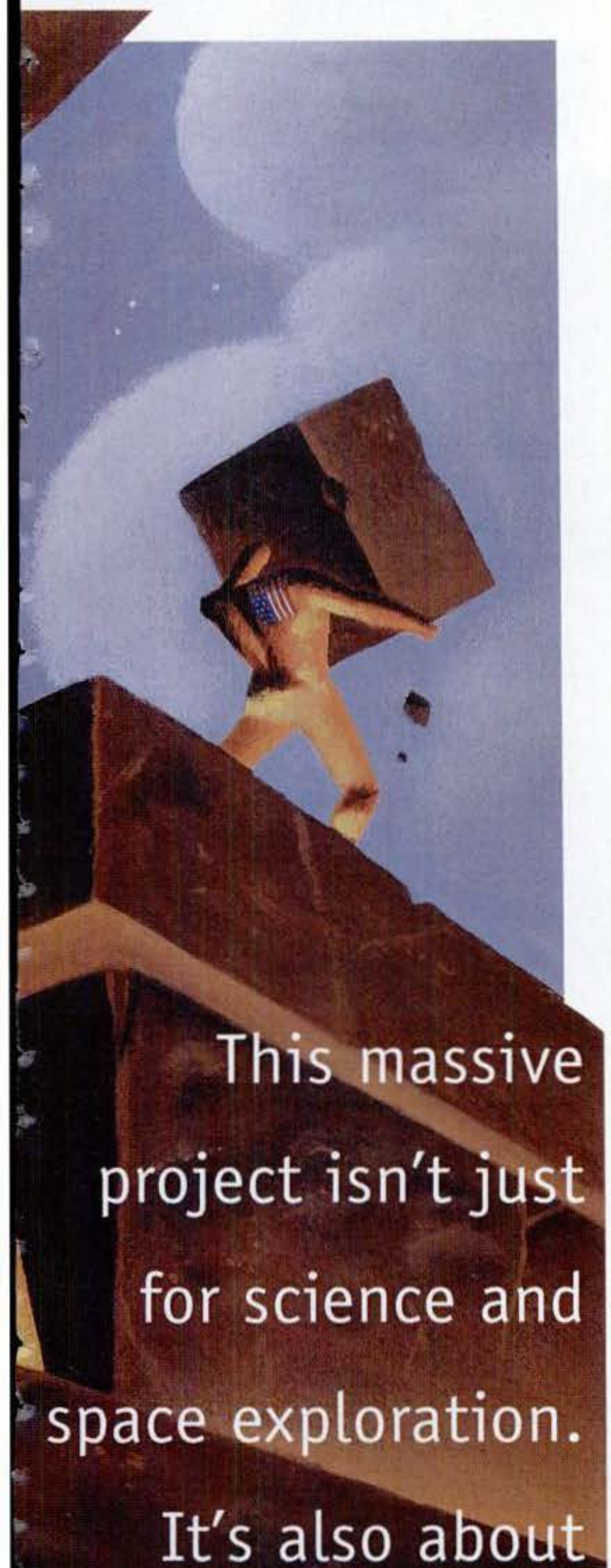

Why Build a Space Station?

By William E. Burrows

EVER SINCE SPUTNIK, AND ESPECIALLY DURING THE COLD war, the score in space has been kept by setting records. To all of the others—Yuri Gagarin's epic flight, Eagle's landing on the moon, Voyager 2's grand tour of the outer planets, and dozens more—add the International Space Station: When completed, it will be the biggest and most complex structure that has ever been built in space.

But the station holds another record that is anything but enviable: It has caused the longest and most rancorous battle in the history of the space age. Although no space project is wholly divorced from politics, the space station has been at the heart of a particularly drawn-out conflict ever since President Ronald Reagan endorsed its construction in December 1983. Only in the final hour, now that the project has moved off the drawing board and onto the launch pad, does the station enjoy the support not only of the White House but also of Congress, a majority of the American public, and 15 other nations. That's a reflection of how the station's mission and potential have grown over time.

Even the station's name reflects the fact that its 15-year gestation period, through one design change after another, spans two dramatically different times. During Reagan's era, the station was named Freedom as an in-your-face

ILLUSTRATION BY STUART BRIERS

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gesture to the Soviet Union. But now, with the cold war over and the United States eager to spread the escalating cost of the program to other countries, including Russia, the project has been rechristened the International Space Station as a gesture toward reconciliation.

As the station's name has changed, so has its purpose. The program is no longer solely about conducting scientific research in the absence of gravity, or about learning how to build a massive structure in orbit, or about establishing the base for a future trip to Mars. The International Space Station is more than merely the next great adventure of the space age. It's also about promoting international cooperation and finding peacetime work for former enemies.

Like the Apollo program that put a man on the moon, the International Space Station is a massive engineering project that will keep a handful of people in space and many thousands employed on Earth. In this post–cold war era, when the U.S. aerospace industry is in decline, the space station program **has created thousands of jobs for highly skilled workers.**

"Not a single dime of this money is spent in space; it's all spent right down here on Earth," says Saunders B. Kramer, a retired research scientist who designed and patented a space station in 1958 while working for Lockheed Missiles & Space. "The guys get their salaries and they go to the tailor, the butcher, the candlestick maker, and the clothiers and the furniture maker and everybody else."

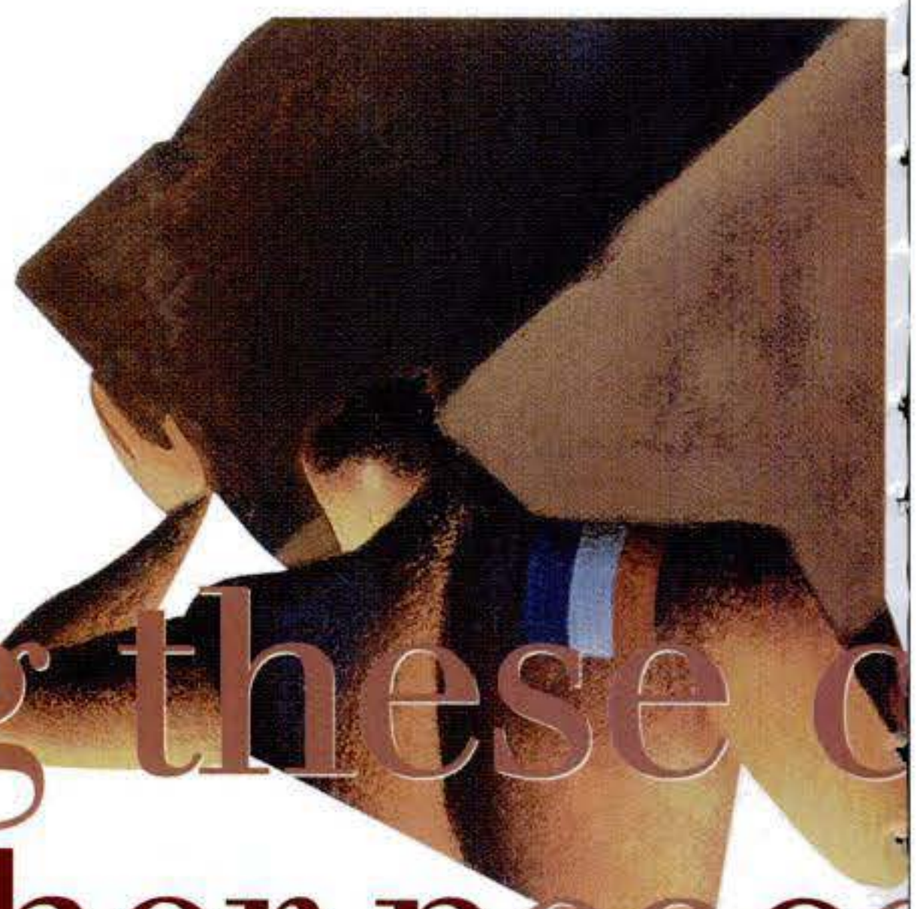
The program has also created jobs in Russia for engineers who might otherwise be recruited to work on foreign military programs. In fact, many of the U.S. and Russian engineers who are now working side by side on the space station are former defense workers who once targeted each other. The station engages 16 of the nation's most technologically advanced nations—the United States, Russia, Canada, Japan, Brazil, and 11 European nations—in a peacetime project of massive proportion.

"It's a political program as well as a science program," says Douglas C. Stone, program manager for the space station at Boeing, the company supervising the station's construction as NASA's prime contractor. "Just getting these countries to work together peacefully is worth more than the price of the station," says Stone. In fact, it amounts to unprecedented international cooperation: the first step toward what space visionaries call a unified "planetary civilization" that will explore space as citizens of Earth, not of individual nations.

To NASA, the space station is a step that follows logically upon the heels of the space shuttle program. Space station supporters correctly point out that one of the space shuttle's key missions is to truck astronauts and hardware into orbit, and that its usefulness (and huge taxpayer investment) will be greatly diminished unless a station is built.

Even so, supporters have at times had difficulty justifying the cost of the station—which will probably mount to more than $40 billion before it is completed. As it is, the station's price tag has climbed over the years from an initial estimate of $8 billion to design and develop it (but not construct it in orbit) to the current U.S. contribution of about $17.4 billion (the figure fluctuates, with Boeing already racking up $600 million in cost overruns). The Russian share is roughly $10 billion, while the European Space Agency is contributing $3.77 billion; Japan $3.1 billion; Canada $850 million; and Italy $550 million separately, even though it is a member of the European group. Congress has earmarked another $13 billion, or $1.3 billion a year, for operating the station through 2012.

It is Congress that Charles D. Walker, a payload specialist on three shuttle missions and a Boeing senior executive for advanced business development, blames for the station's spiraling cost. "They [Congressmen] have no experience with technical programs, no experience with government and industry working on technical design, development, and deployment," yet they want to micro-



"Just getting these c
to work together peace
is worth more than the price o

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manage the huge program, he says.

But there is plenty of blame to go around. One White House budget official, Frederick N. Khedouri, complains that NASA consistently underestimates the program's cost. "They always talk about a stripped-down model that doesn't exist," he says.

The debate has been going on at least since April 1960, when representatives from the fledgling space industry held a manned space station symposium in Los Angeles sponsored by NASA, the Rand Corp., and the Institute for Aeronautical Sciences. Squabbling broke out regarding what a station should be, where it should be put, and how to build it. Everyone agreed that a space station would be good, but not on what it was good for.

President Kennedy's decision in May 1961 to send Americans to the moon put the station on a back burner, since there was insufficient money for both projects. But even as work on Apollo moved toward its crescendo, NASA's space station designers quietly decided on a modular concept—a giant Tinkertoy—that would be built and supplied by a winged vehicle shuttling back and forth from Earth to orbit. Unlike the Mercury, Gemini, and Apollo astronauts, who parachuted out of space as though they were leaving the scene of an accident, those on the shuttle would return home in a more dignified gliding airplane.

When President Nixon approved the shuttle in January 1972, the station was postponed again. The heart of the problem had to do with a debate that continues to this day: Are people necessary for space exploration, or can machines work better and cheaper by themselves? Critical also was a budgetary pie of finite size. These key factors created a formidable number of enemies for the station.

There was no doubt where most of the science community stood. Scientists opposed the station because they felt its huge expense would drain money from much more useful research programs. In 1983, even as Reagan pondered whether to approve the station, the National Research Council's prestigious Space Science Board urged NASA to postpone it for at least 20 years because there was "no scientific need" for a station in space. But the scientists lost to NASA's persuasive administrator, James M. Beggs, who convinced Reagan that the station was "the next logical step" after the shuttle and that, furthermore, it would embody America's leadership in the world and stimulate free enterprise.

Nevertheless, opponents in Congress and elsewhere continued to hammer at the station throughout the

A Big Business

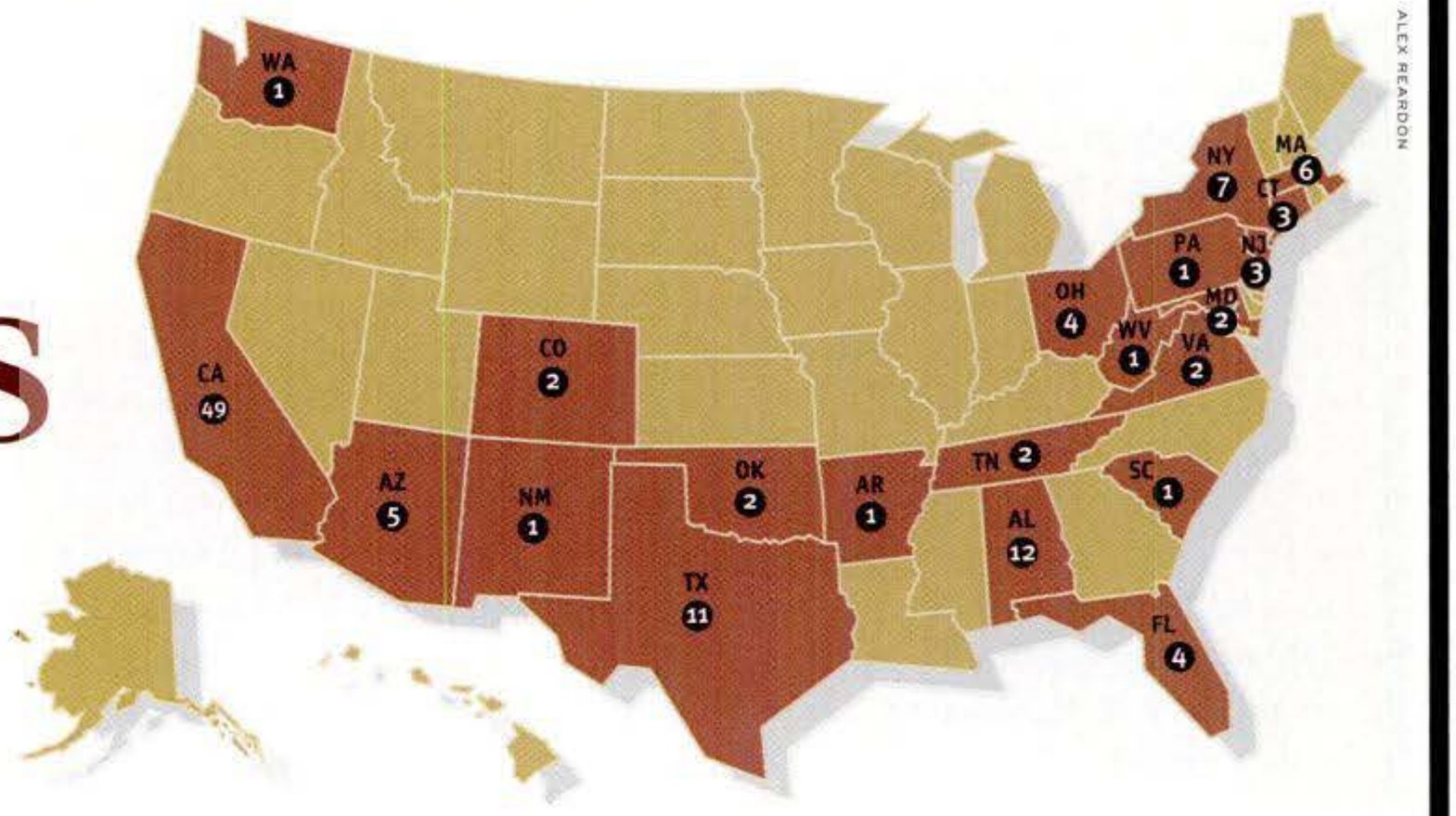
MORE THAN 5,000 people are employed by Boeing's space station program in the United States, with at least another 5,000 working for subcontractors, suppliers, and NASA itself. This spreads to perhaps 30,000 more who benefit indirectly, and then to uncounted thousands who live off them.

Boeing has subcontractors all over the United States, including 49 in California alone (see map, below), plus 35 in Europe, 24 in Canada, nine in Japan, and two—Energia and Khrunichev—in Russia. The station is therefore the product of a tightly constructed international conglomerate.

Boeing's contract is worth $7 billion. Lockheed Martin, which holds the next biggest contract, is in for $758 million to supply solar arrays and other hardware. Energia, the prime contractor for the Russian Space Agency, has a contract worth several billion dollars, although the value fluctuates with the changing worth of the ruble.—*W.E.B.*

WHERE THE JOBS ARE

WITH 120 MAJOR subcontractors in 21 states, the ISS means thousands of jobs for U.S. workers. This map shows the number of companies in each state.



ALEX REARDON

ountries fully he station."

Space stations that never were www.popsci.com

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The View from Russia

RUSSIA WAS THE FIRST nation into space, and has long been recognized as the world's leader in building space stations and conducting long-duration space missions. So turning over the reins to an international partnership isn't easy for many Russians. Some, including legislators and veteran cosmonauts, see the transition from Mir to the International Space Station as a regrettable loss of independence and preeminence.

In response, the station's powerful supporters—chief among them President Boris Yeltsin—accuse its opponents of representing the "old thinking" of the Soviet era. In the new thinking, international alliances and financial support are more important than independence.

The vast majority of the Russian public seems to agree. In a country where pensioners, teachers, and even nuclear weapons custodians are not being paid regularly, workers are eager for steady jobs. Space officials point to the Western money flowing into Russia for commercial launch services and space hardware sales. They also boast that the station is actually costing the Russian government nothing at present, since it is funded by bank loans to be repaid in the future.

Yuriy Koptev, director of the Russian Space Agency, stresses that while Russia pays for only a fifth of the project, it gets two-fifths of the lab space on ISS. Once completed, he claims, the station will give Russia twice the on-orbit research capabilities of Mir, at about the same operational cost.—*James Oberg*

Balloons celebrating space exploration grace May Day festivities in Moscow's Red Square.

1980s and well into the '90s. In 1991, the 40,000-member American Physical Society turned thumbs down on the station, saying that a vigorous space science program could be accomplished without it. The following year, representatives of a number of foundations and societies told Congress that there was no evidence that medical research in space helped patients on Earth. Dr. David Rosenthal of the Harvard Medical School attacked the notion that either cancer or AIDS could be combated any better in space than it could on Earth.

The station had its closest shave in 1993, when it survived a challenge in the House of Representatives by only one vote. But intense lobbying and a publicity blitz by industry, plus arm-twisting by Vice President Al Gore, finally turned the tide in 1994, when federal lawmakers voted 278 to 155 to provide $2.1 billion in funding for the following fiscal year.

By 1994, many scientists had changed their minds about the project and either weighed in for it or simply sat out the debates that raged in Congress. The change came for several reasons. That year, NASA shifted its public relations focus away from science, concentrating instead on jobs and cooperation with Russia. The science plan hadn't changed, but the project now offered a lower-profile target for opponents in the science community, who didn't want to take on the jobs issue or seem to impede closer relations with Russia.

Many scientists were also afraid to challenge the president, members of Congress, and the aerospace industry. As Columbia University astrophysicist David Helfand explains, defying NASA on its pet manned programs can bring reprisal to space scientists where their own grants are concerned.

Today, with the first launch approaching, at least one sector of the scientific community is excited about the prospects for research aboard the station: the 900 scientists with an interest in microgravity who are preparing experiments to send to the station. There, these experiments may shed light on the behavior of plants, animals, protein crystals, flames, molten metal, and other substances in the absence of gravity. There's no guarantee that these experiments will lead to anything as dramatic as a cure for cancer, although NASA and Boeing have raised that possibility. Yet in science, sometimes the best discoveries are the unexpected ones. "Serendipity will rear its lovely head," says Kramer, the former Lockheed scientist. "We'll find 10,000 things to do on the station that nobody's thought of or even imagined."

And yet even today, many scientists outside the field of microgravity research continue to criticize the station. The research planned for the station is "good science, but it's not science that would ever justify an ex-

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penditure like the space station to do," says Robert L. Park, a University of Maryland physics professor and the director of the Washington, D.C., office of the American Physical Society. Park is among those who believe that science would be better served by less costly robotic missions. "Robots improve every year, while humans have basically been the same for 35,000 years," he says.

For its part, NASA hopes to bring down the cost of the station by attracting paying customers. Some 30 percent of the research space in NASA's laboratory facilities has been set aside for commercial users such as pharmaceutical and biotechnology companies. Rep. Dana Rohrabacher of California, who chairs the House space subcommittee, has even suggested that the station be used for advertising and Hollywood filmmaking—but commercialization is being stalled by bureaucratic red tape. Bill Wisecarver, the exasperated director of commercialization for the station, complained last December that NASA's own space experts, grounded as they are in science and engineering, just "don't understand how the economics of the private sector work."

NASA is also contending with Russia's painfully slow work on the station's Service Module—the all-important power, control, and habitation structure from which the rest of the structure expands. The Service Module is already more than 60 days behind schedule. The cash-starved Russian Space Agency is also supposed to provide the propellant module and the resupply operation.

The Russian agency and its Energia and Khrunichev contractors desperately want to be viable partners in this international enterprise, not only to ensure their own survival and help rebuild their nation's crippled economy, **but because space technology remains Russia's crown jewel** and deepest source of pride. At the same time, the Russian legislature's unwillingness to honor the country's financial commitments to the station reflects a preoccupation with problems closer to Earth. "The biggest political risk," Boeing's Stone frets, "is dealing with the Russians."

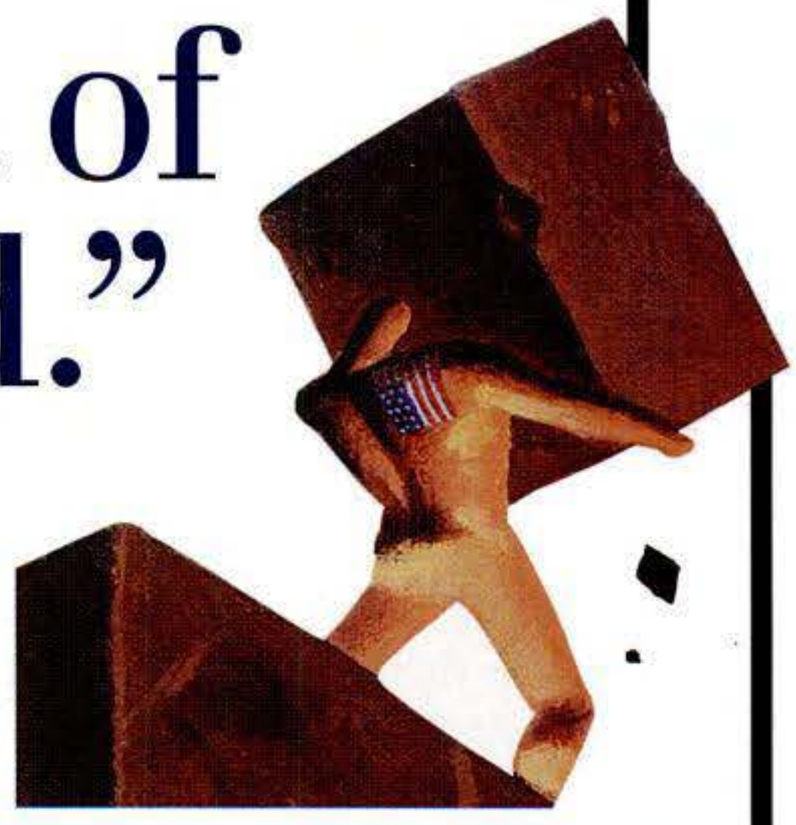
"If the Russians pull out of the Service Module, yes, we can build the space station," says Gretchen W. McClain, NASA's director of space station requirements. But if they renege on the propellant and resupply operation too, she says, the station would be in serious trouble. "If they pull out altogether tomorrow, it would be a bad day on the Hill. I probably could see the program getting canceled."

But McClain remains optimistic. "It's been a battle and a struggle, but what's intriguing to me is that it is a concept that was started years ago and it has continued to survive a lot of challenges and upscaling and downscaling. For the first time," she says, "we've moved off of a paper study, which this program was on for years, and you're seeing hundreds and hundreds of thousands of pounds of hardware being completed."

Meanwhile, public support for the station appears solid. In a random telephone survey of 1,510 Americans conducted by Yankelovich in late 1997, 28 percent "strongly favored" carrying out a program to build a permanently manned space station, while another 42 percent "somewhat favored" it. For many Americans, space exploration remains a grand adventure that is well worth the money.

"If the shuttle and space station program went away tomorrow, you'd see the unmanned program go away," says McClain. "I believe the heart and soul of space is the human element. People can relate to that. You've got the young kids thinking, 'God, I'd love to be an astronaut. Wouldn't it be great to be up there, to touch and feel,' and I think that's part of the excitement about it." ◆

'We'll find 10,000 things to do on the station that nobody's thought of or even imagined."



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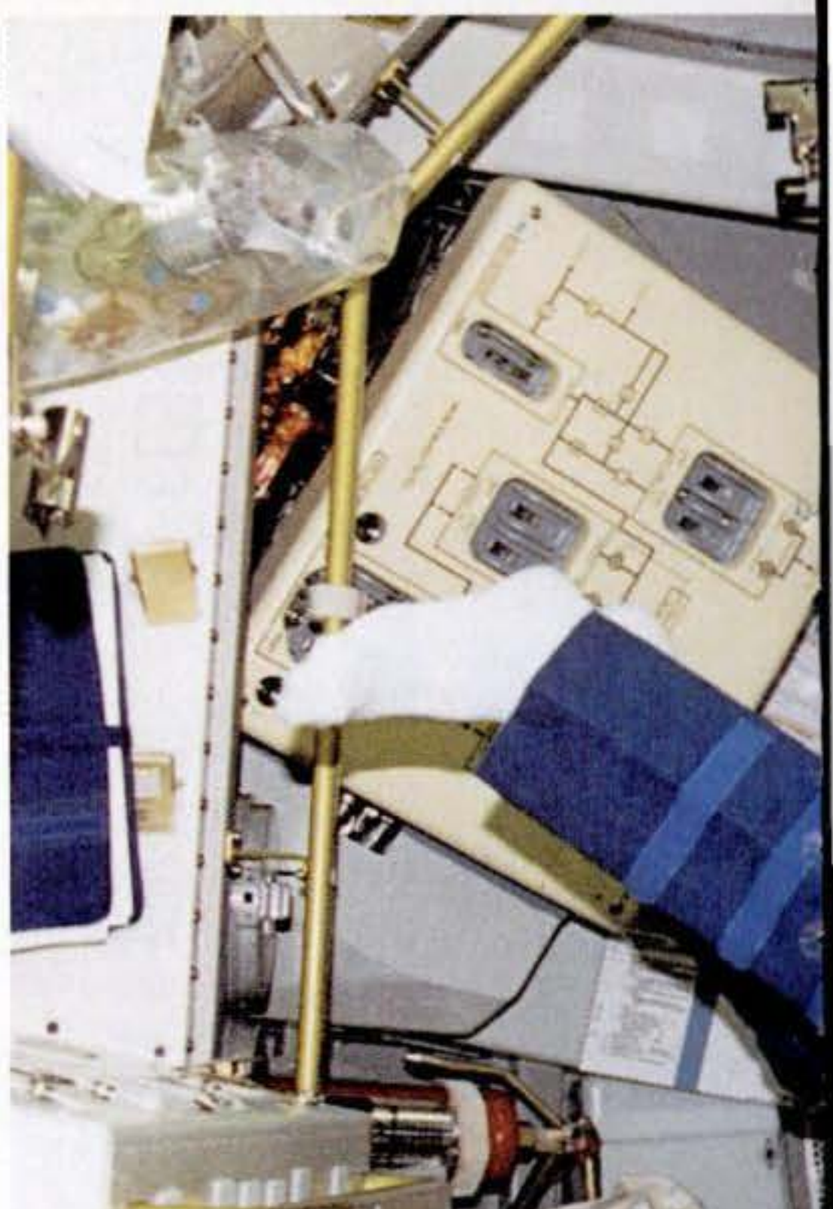
24 Hours in Space

Out of this world: A day in the life of an astronaut.

By Mark D. Uehling

SHORTLY BEFORE HOUSTON'S DEFINITION of dawn, International Space Station, Node 2. The year is 2006. You rub your eyes and stretch, still zipped into a duffel bag that holds you securely in your closet-cubicle. In here, it is as quiet as the desert and as dark as the womb. You have slept better than at home. But nature calls. You float to the ISS restroom, hoping to arrive before your 64-year-old mission commander, a one-time vice president of the United States.

But as it turns out, the head is occupied. So it's on to the "shower." There is no spray: With so little gravity on the station, water floats instead of falling. But you are grateful for that hose, which dispenses a gallon of water that you smear onto your skin. The detergent emerges as a narrow cord of paste with the consistency of Crisco. The same stuff



NASA (4)

In the weightless environment of space, everyday activities present new challenges. Experiences on the space shuttle have helped prepare astronauts for life aboard the International Space Station. Clockwise from top: Susan L. Still entering data into a computer; Loren J. Shriver eating chocolate candies; Brian Duffy applying shaving cream; Bjarni V. Tryggvason sleeping on the "floor."

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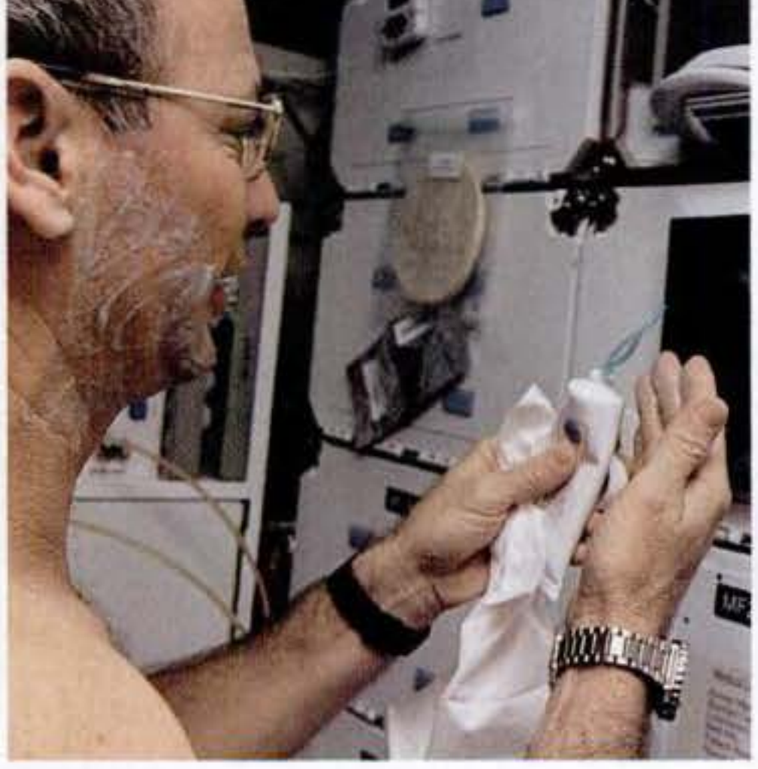

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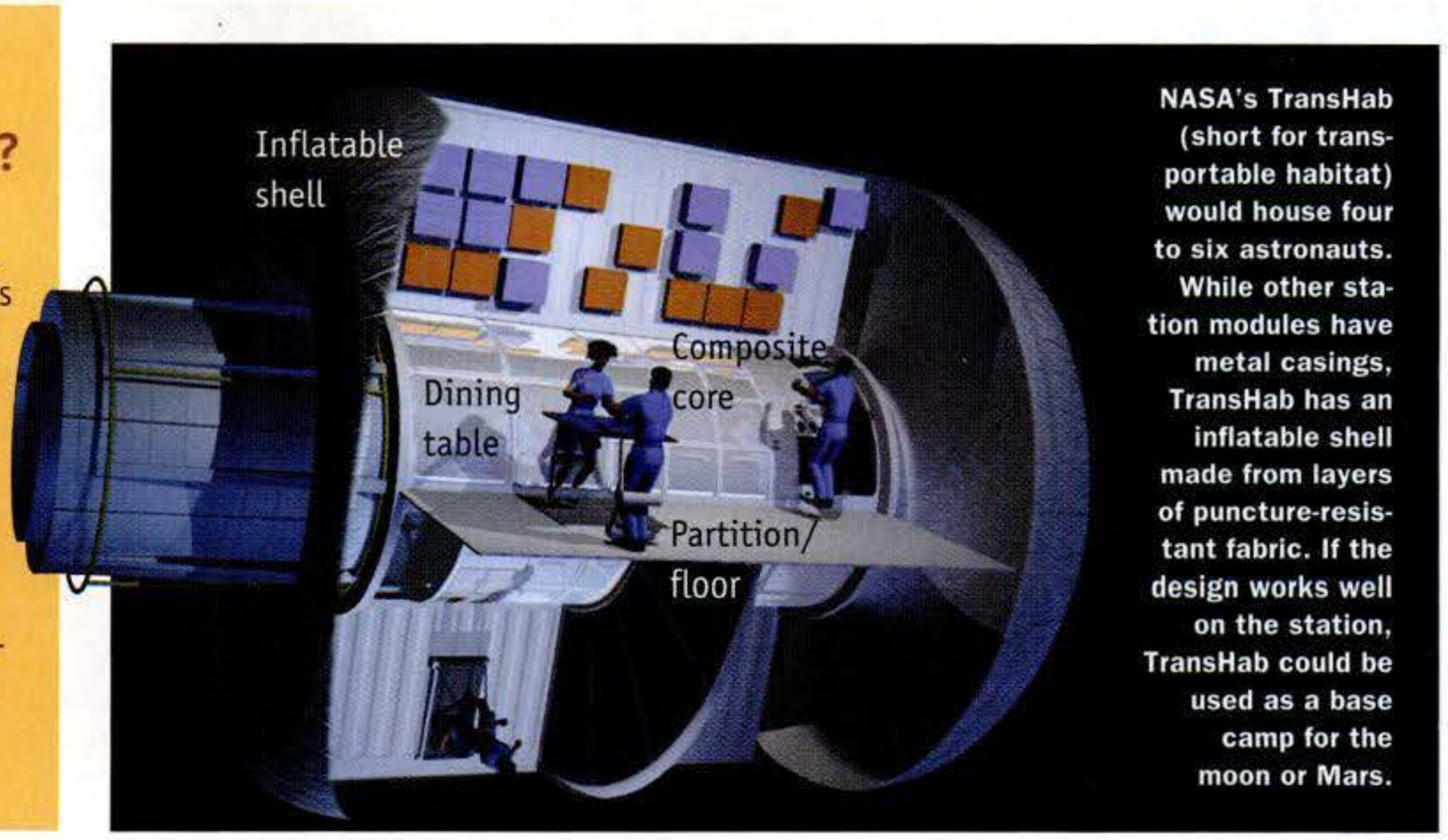
WHICH HOME SWEET HOME?

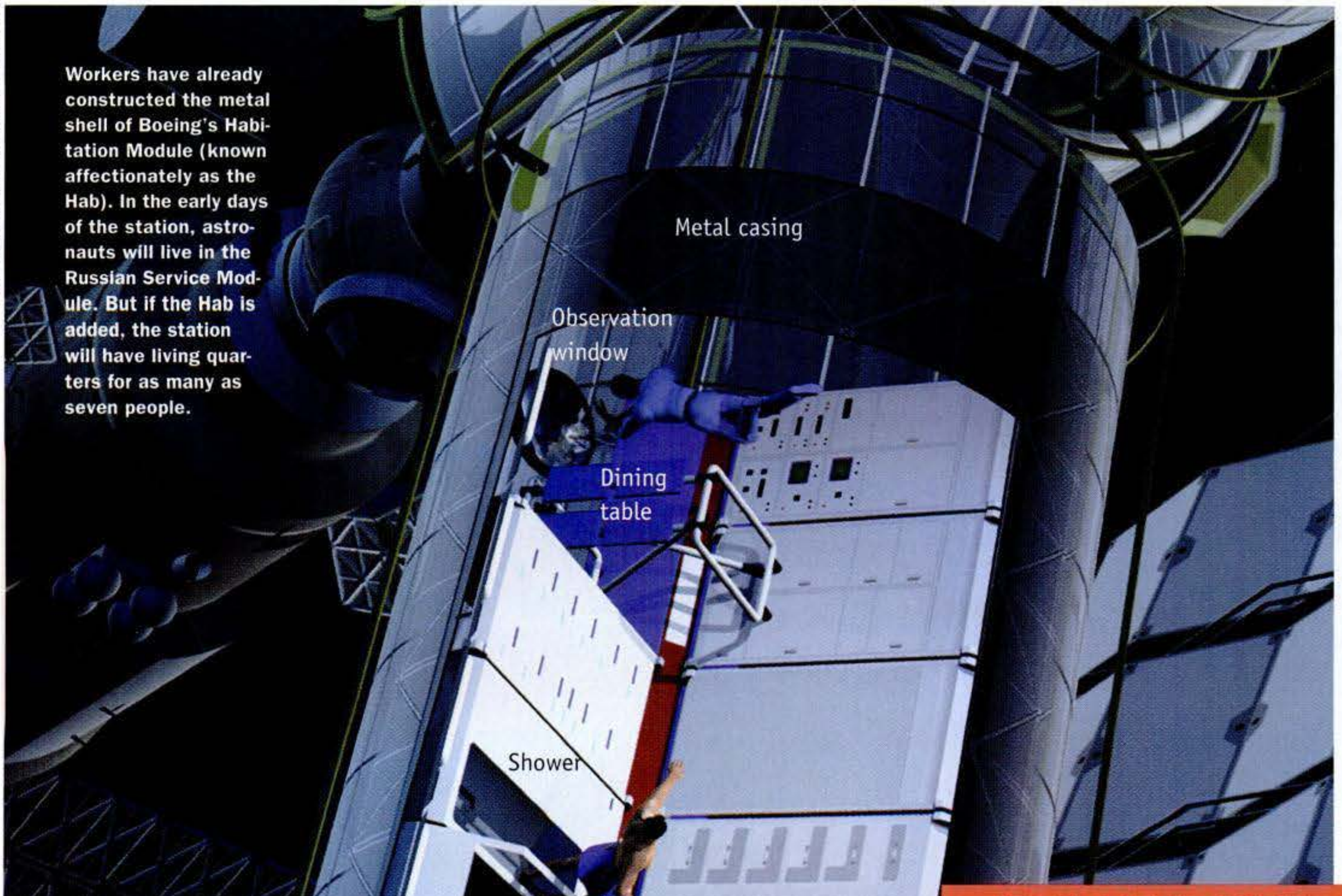
NASA HAS issued a stop-work order on the station's Habitation Module (below), and is considering replacing it with a lighter, inflatable module called TransHab (right) that features the same amenities. NASA expects to make a decision by the end of this year.



NASA's TransHab (short for transportable habitat) would house four to six astronauts. While other station modules have metal casings, TransHab has an inflatable shell made from layers of puncture-resistant fabric. If the design works well on the station, TransHab could be used as a base camp for the moon or Mars.

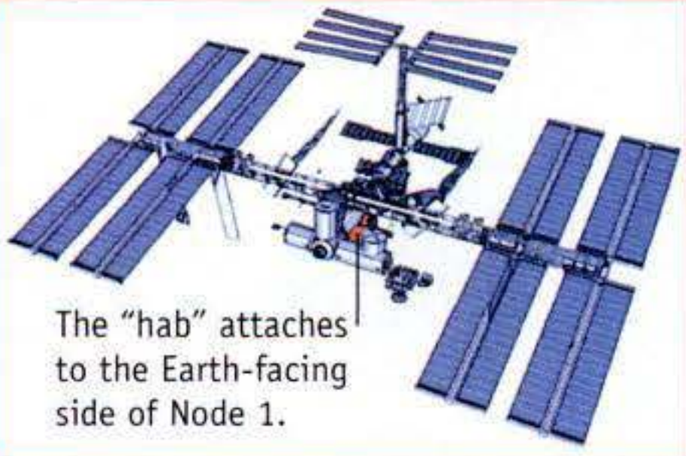
BOB SAULS/JOHN FRASSANITO & ASSOCIATES (2)

Workers have already constructed the metal shell of Boeing's Habitation Module (known affectionately as the Hab). In the early days of the station, astronauts will live in the Russian Service Module. But if the Hab is added, the station will have living quarters for as many as seven people.



ITS PLACE IN SPACE

The Habitation Module, to be launched in December 2003, will be the last piece.



The "hab" attaches to the Earth-facing side of Node 1.

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was on the shuttle, with a fishy odor that goes away when you lather up.

After drying yourself, you vacuum up the globules of water, hair, and soap. The moisture will be recycled into something you will soon drink. You don the same sweaty jumpsuit you have worn for the past week, and emerge. (Congress didn't splurge on a laundry for your 90-day ISS mission.) The temperature of the station—set manually by the crew but linked to sensors that automatically regulate humidity to prevent the windows from fogging up—is 70°F. That's 25 degrees cooler than the boiler-room environs of the old Mir. Another day has begun.

Life-support systems on the American side of the ISS, you know, are the most advanced ever. NASA engineers can supply cleaner air, purer water, better food, and more sanitary toilet facilities than on the space shuttle. Life aboard the station may not be easy, but it is significantly healthier and more pleasant than in the past, allowing you to focus more intently on the scientific research and station-maintenance chores that occupy you for about 9 hours a day. Back on Earth, you hear, perennial NASA critics still cross their fingers about how seamlessly all of the international equipment and software will work. But there have been no major glitches so far.

That's what NASA expected. It had never professed any public concern that American lives would be endangered by sturdy but inexpensive Russian equipment. "The Russians have excellent engineers and excellent designs," said Jim Reuter, the leading NASA engineer for environmental control and life support. That was the whole point of going with them. As an example of backup systems within backup systems, Reuter had noted, *either* the Russian or the American air system could supply the needs of the entire station. But even he had conceded that there are so many interconnected pieces of life-support gear from so many countries and suppliers that it would be impossible to predict how they would interact. "It would not take much to have a catastrophic event," he had said somberly long ago. "I do lie awake at night sometimes."

This morning, though, you are not thinking about disasters as you slip your stocking feet into the restraints on the floor of the galley. It helps to be anchored while eating. The kitchen on the station, for the first time in NASA's history, has refrigerators and freezers. It may not sound like much, but it is a giant step forward. For the first 30 years in space, all food was kept at room temperature. Only now, in the 21st century, can refrigeration allow NASA to supply one of the most-requested items since shrimp cocktail: a deliciously intoxicating beverage, dear not only to humans but to mammals everywhere: milk. Your commander says he drinks four bags a day—the bar codes should confirm that—to help with bone loss.

NASA

To test biological systems for recycling oxygen, Lockheed Martin scientist Nigel Packham seals himself in an airtight chamber with 30,000 wheat plants for weeks at a time.

"A glass of nice cold milk was requested for years," says Charles T. Bourland, a food scientist at NASA's Johnson Space Center. "It defeated all the technicians in the world. There is a delicate flavor and delicate structure there." Powered milk was summarily rejected. "It was not real cold. We did some work a number of years ago with a formula. We had some people who added some fat to it. But it wasn't that good." The refrigerator proved to be an easier solution. Gratefully, you gum some corn flakes and mix them in your mouth with milk sucked out of a straw.

Later in the day, thanks to another kitchen appliance, you'll eat a frozen TV dinner just like the ones sold in supermarkets. The combination convection/microwave oven automatically thaws your food (using heat blown around the oven), then zaps it with microwaves (working just as they do on Earth).

The refrigerator, freezer, and oven mean that you and your colleagues eat a healthier diet. "The shuttle food was low in fiber. The International Space Station food can overcome that with salads, fruit, vegetables, apples, oranges, broccoli," Bourland had predicted. Now, with these foods delivered by the space shuttle a few times a year, you no longer have to take pills for the constipation that is common in space.

One appliance is missing from your kitchen: a dishwasher. Instead, you wipe down your magnetic silverware with moist antiseptic towelettes similar to those at KFC. It doesn't sound hygienic, but your commander reminds everyone that shuttle astronauts just *licked* their silverware clean. The empty food containers, if Russian, will be ejected into space to burn up on re-entry to the atmosphere; American garbage will be returned to Earth on the shuttle.

It's time to get to work.

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Today, Houston has asked you to begin swapping out the Unibeds, assemblies of tubes that are part of the station's elaborate water purification system. A few hundred gallons of water for the station are carried into orbit or supplied from fuel cells in the shuttle. But water up here quickly meets the same dirty fate it does on Earth. Except up here it is returned to the tap in a pristine state 8 or 9 hours later.

Your background is as an Air Force pilot in the Persian Gulf, so you're not an expert at laying pipe. Fortunately the ISS plumbing is easy to take apart: The parts have quick-disconnect, or Q-D, joints that are spring-loaded.

There are separate Russian and American systems for recycling air and water. The Russians barely monitor the water in orbit, pointing to their healthy crew members as proof the system is working. Your fellow Americans take a top-of-the-line approach, providing ultrapure water cleaner than that in many U.S. cities.

Like the shuttle before it, the station uses air pressure to whisk water away from the human body or a sink's drain. This mixture of air and water doesn't settle into the easy order that it does under the influence of gravity. So separating the two requires a large centrifuge spinning at 6,000 rpm. It recovers 85 to 95 percent of the water in your urine, leaving behind a pungent-smelling brine the color of ice tea. You have to marvel at the system. Instead of venting water overboard, as on the shuttle, the American system transforms the water into steam and condenses it to a liquid again before additional stages of chemical, heat, and mechanical treatment. Then iodine is added to ensure that pipes and fixtures do not harbor bacteria from within the cabin.

You can taste the iodine. Everybody can. "Even though we know it's clean analytically, we wanted to know if people would drink it or not. In general, people have rated it as something they could easily use as their everyday water," the ISS water guru, Robert Bagdigian, had said. "The main complaint is that it tastes medicinal."

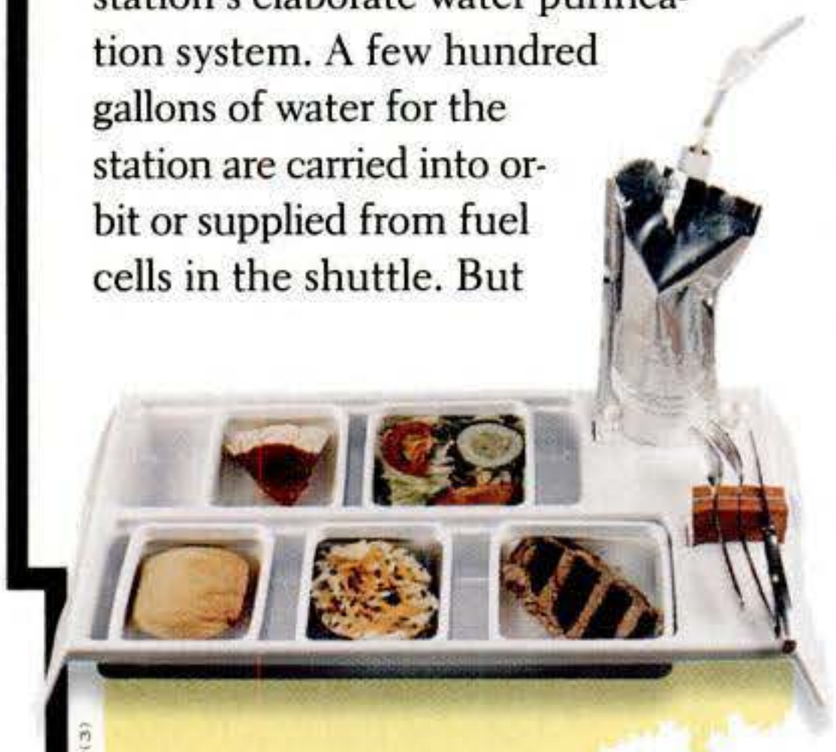
Water consumption, oddly, varies widely from culture to culture. Not until American Shannon Lucid stayed aboard Mir did anyone realize that astronauts typically drink more than twice as much water as cosmonauts, who imbibe just 1 liter per day.

All of which reminds you: The bathroom has opened up. The hose for urine is familiar from the shuttle. (The man holds a small funnel near his penis; the woman presses a similar but vented receptacle against her skin.) In both cases, weak air suction—but never enough to form a seal with your body—draws the urine away. You can feel the air, but it doesn't hurt. Once it's in the tube, the urine washes over small white tablets of oxone and sulfuric acid that everyone up here calls the "string of pearls," preventing the formation of potent ammonia.

Part of the cleaner cabin environment, you admit, can be traced to the receptacle for solid human waste. Prior to sitting down, you snap a polypropylene bag into a canister; a ring on the bag holds it in place. The bag itself is porous—that allows air suction, once again, to whisk feces away from the body. When you're finished, you place a lid on the bag. Finally, using the orbital version of a kitchen trash compactor, you position a huge piston over your bag, and a motor smashes the piston down on top of the other astronauts' squashed bags. Every few days, depending on the crew size, a new empty canister is swapped in. As housekeeping tasks go, it's not bad at all.

The new outhouse is definitely superior to those on the shuttle and Mir. They not only forced you to look at the excrement of your colleagues, but also caused feces to dry out and circulate through the cabin as a fine, unhealthy powder. "We've made a lot of steps in the fecal area," says Hubert J. Brasseaux Jr. at NASA's Johnson Space Center. "Years ago, the shuttle toilet used to fail all the time."

Same story with the air. By many accounts, the atmosphere on the shuttle and Mir was skanky—like high-school locker rooms that hadn't been



NASA (3)

Things Taste Better at Home

WHY DOES A third of the food sent into space come back to Earth uneaten? The problem may be physiological: Some astronauts insist taste buds function differently in orbit. Others cope with motion sickness and stressed-out stomachs.

Then there's the food itself. It's preserved using techniques that are perfectly safe, and studies of returning astronauts show they get the nutrients they need. But irradiation and freeze-drying don't always yield foods with authentic flavors and juiciness.

POPULAR SCIENCE sampled a strip steak, with salt applied in a liquid solution, as in orbit. The meat was dry and, to be charitable, chewy. Lemonade out of a foil pouch had metallic overtones. And cottage cheese with nuts had the texture of spackle. All of which is why NASA is looking forward to refrigerators and freezers on the new station.—*M.D.U.*

Astronaut food includes TV dinners with foil drink pouches (top), M&M candies (above), and shrimp cocktail (right).

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mopped in years. "We had problems with particles floating around," concedes Charles Ray, Life Support System leader at NASA Marshall. "They had to make an improvement." Indeed they have. So have the Russians, who were not always able to control the smell of garbage on the overheated Mir.

The ISS air-filtration systems, which vent some unwanted gases overboard, pay much closer attention to a long list of potential contaminants. In ground tests, the engineers scanned for as many as 250 trace contaminants; in orbit, they monitor 25 in real time. The air system now screens out particles as small as 0.3 microns. By comparison, the air system on the early shuttle only removed particles down to 280 microns in size. Nearly every material onboard is tested for outgassing.

It's time for you to check on one of those experiments, a small soybean plantation. The commander has privately threatened to toss the whole dirt-filled box overboard. But it represents the next step in life support: a completely closed air-and-food loop, with plants grown and harvested in space. Plants and microorganisms could even help remove contaminants from the water supply. It is that sort of research that will be necessary if humans are ever to establish settlements far beyond Earth.

Back in the late 1990s, NASA's Don Henninger had said it might even be possible to put some of those more experimental approaches to eternal housekeeping problems into front-line service on the ISS. "These technologies have proved very exciting on the ground and have definite potential in the station," said Henninger, the agency's chief scientist for regenerative life support. Biological approaches to supplying food, water, and air could not only save power aboard the station, but could also reduce the number of resupply trips required.

Even before the space station was launched, engineers down in Houston had locked themselves up in isolation chambers for 30 days, 60 days, 90 days, even as long as 400 days at a stretch, to test prototype air- and water-recycling systems using wheat and other edible plants.

Maybe someday you'll have fresh bread on the station. But even with today's TV dinners, you already spend 4 hours a day on meals and hygiene. Exercise is prescribed for 2 hours a day. That leaves you just an hour of free time for the simple pleasures of life in space: The view of Earth through the window. A letter e-mailed from your family. Microwave popcorn with a movie. And the friendship of the crew members with whom you share this tiny world. ◆

Down the Drain

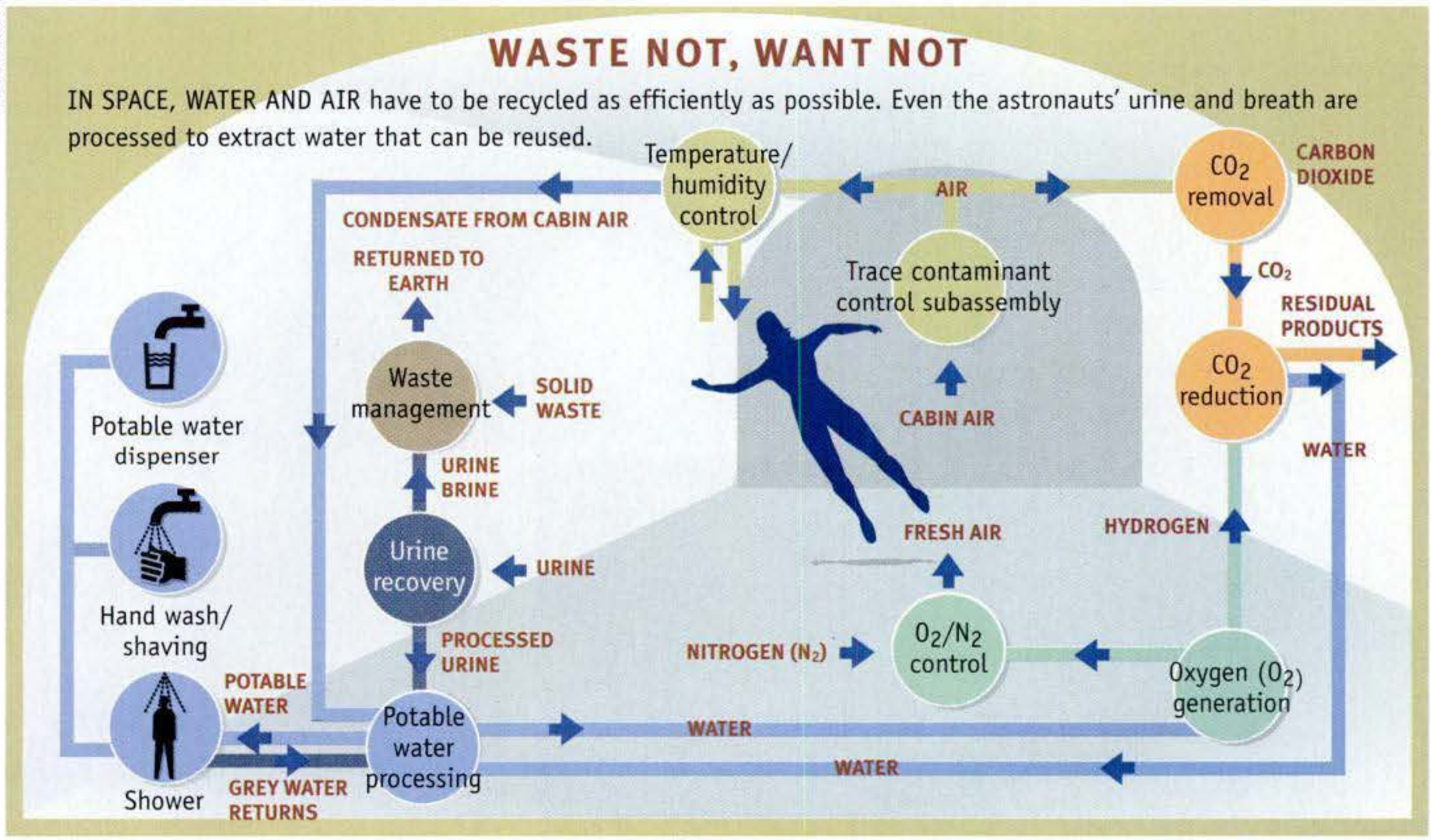
TO TEST the water-recycling systems planned for the station, scientists use this recipe:

WASTEWATER STREAM	AMOUNT (%)
HANDWASH	29
SHOWER WATER	24
HUMIDITY CONDENSATE	23
FUEL CELL	12
URINE DISTILLATE	10
ORAL HYGIENE	2
TOTAL	**100%**

ALEX REARDON

WASTE NOT, WANT NOT

IN SPACE, WATER AND AIR have to be recycled as efficiently as possible. Even the astronauts' urine and breath are processed to extract water that can be reused.



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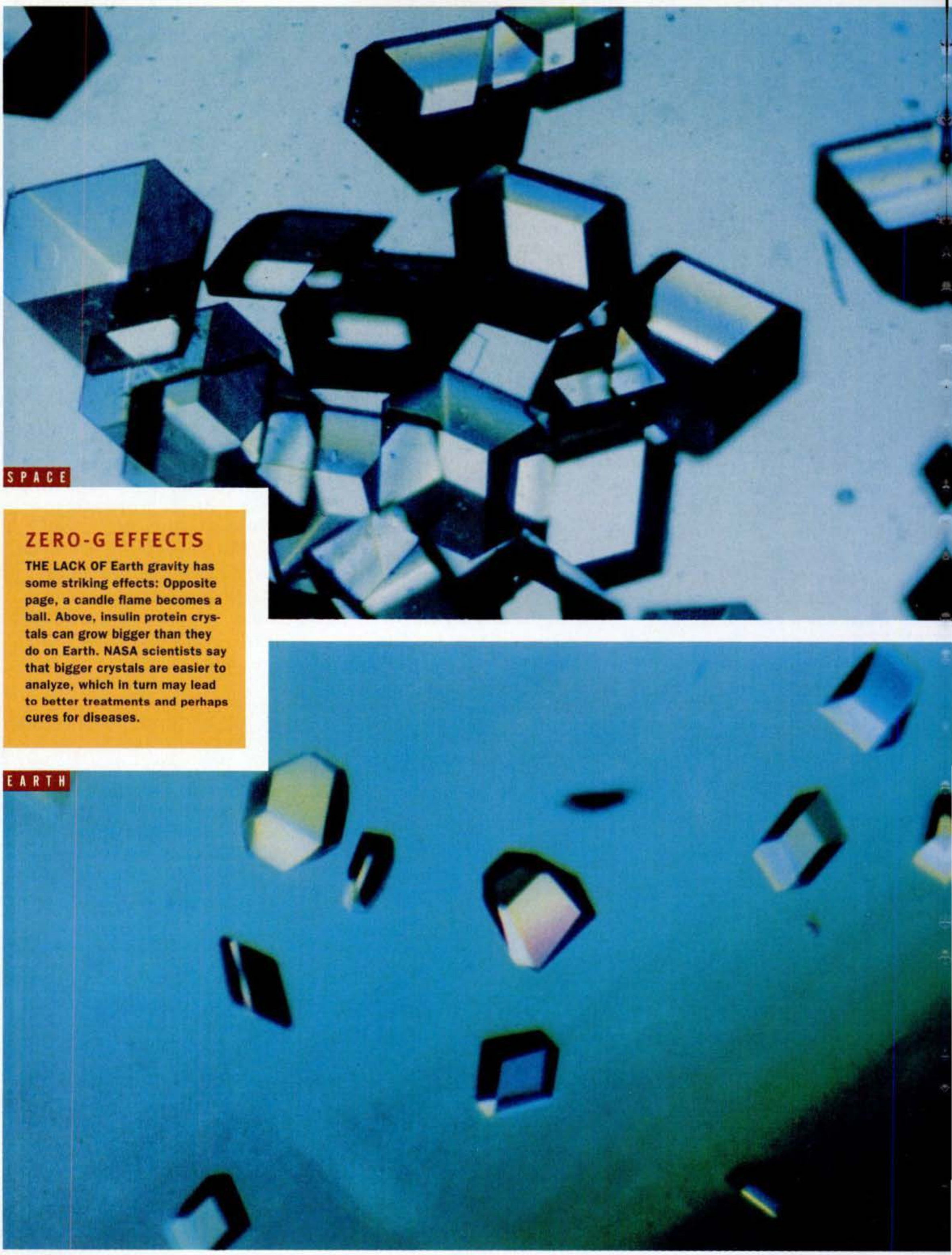

SPACE

ZERO-G EFFECTS

THE LACK OF Earth gravity has some striking effects: Opposite page, a candle flame becomes a ball. Above, insulin protein crystals can grow bigger than they do on Earth. NASA scientists say that bigger crystals are easier to analyze, which in turn may lead to better treatments and perhaps cures for diseases.

EARTH

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By Mariette DiChristina

Weird Science

Research on the space station is really out there.

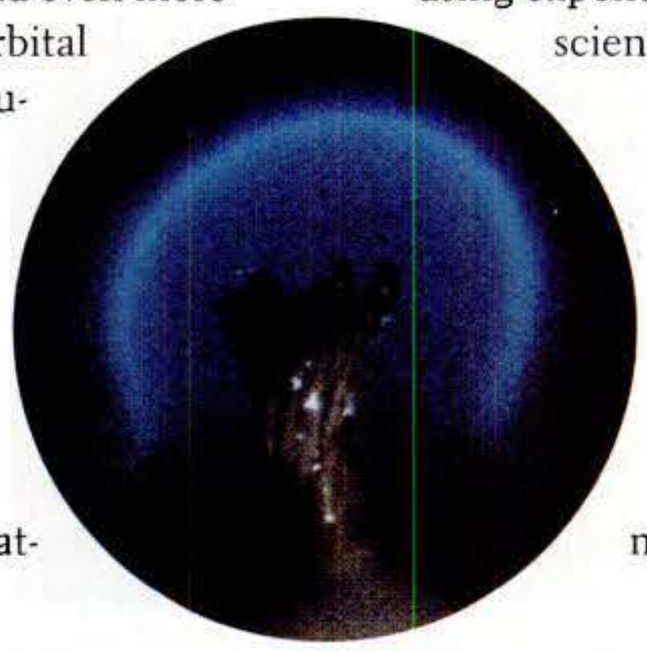
SO MAYBE YOU'RE THINKING THAT BEING IN space would be cool, but you're wondering what on Earth—well, *off* Earth—is so special about conducting science in a lab aboard the International Space Station? NASA has an answer for you: Microgravity.

Microgravity, which translates to one-millionth of the force felt on Earth, is the only gravity that will exist on the space station. How weak is that? While a coin dropped from 6 feet on Earth takes half a second to hit the ground, aboard the station the same coin would take 10 minutes.

The dearth of gravity causes some striking effects—carrots can turn and grow upward, forming a "u" shape, and a candle flame becomes a blue ball. NASA researchers say that without the interference of Earth's gravity, many otherwise-hidden processes could be revealed in basic science research. "This will be a lab that will be unique in the world," says John-David Bartoe, the station research manager at Johnson Space Center in Houston. While there are no guarantees about practical applications, NASA researchers say, space station research could lead to new treatments for diseases, better materials and alloys, and even more efficient use of fuels. With the station's orbital vantage point and mission duration, instruments aboard could also conduct Earth- and space-science studies.

The completed station will have six laboratory modules: one each from the United States, Europe, and Japan; two from Russia; and a sixth module, built in Japan and operated by NASA, with a 2.5-meter centrifuge. There'll also be outside attachment points for experiments that need to be exposed to space. The station will enable projects of longer duration than the shuttle, and its facilities will be bigger and freer from vibration than the Russian Mir. As currently scheduled, the experiments will be launched between November 1999 and December 2003. Some science work will be conducted before all the equipment is aboard the station. There will be several main areas of research, and most of them share the goal of understanding how various things work without the influence of Earth gravity.

Of course, not everyone agrees that research in microgravity is so useful—and indeed, many researchers have harshly questioned the station's potential value to science. "Most scientists regard microgravity as one of the least important variables you can have," scoffs Robert L. Park, a University of Maryland physics professor and the director of the Washington, D.C., office of the American Physical Society. While NASA researchers point to the benefits of having humans to intervene in case of potential problems or to redirect an experiment, others prefer using expendable, less costly robotic missions to solve scientific questions in space.



But since science will be conducted aboard the station despite the debate, what will that science really be like? For the astronaut planning to conduct a series of experiments, the work would begin the night before. On a laptop, he would review the research plans and step-by-step procedures, as well as the location of needed equipment. A conversation with the

INFOGRAPHICS BY DON FOLEY

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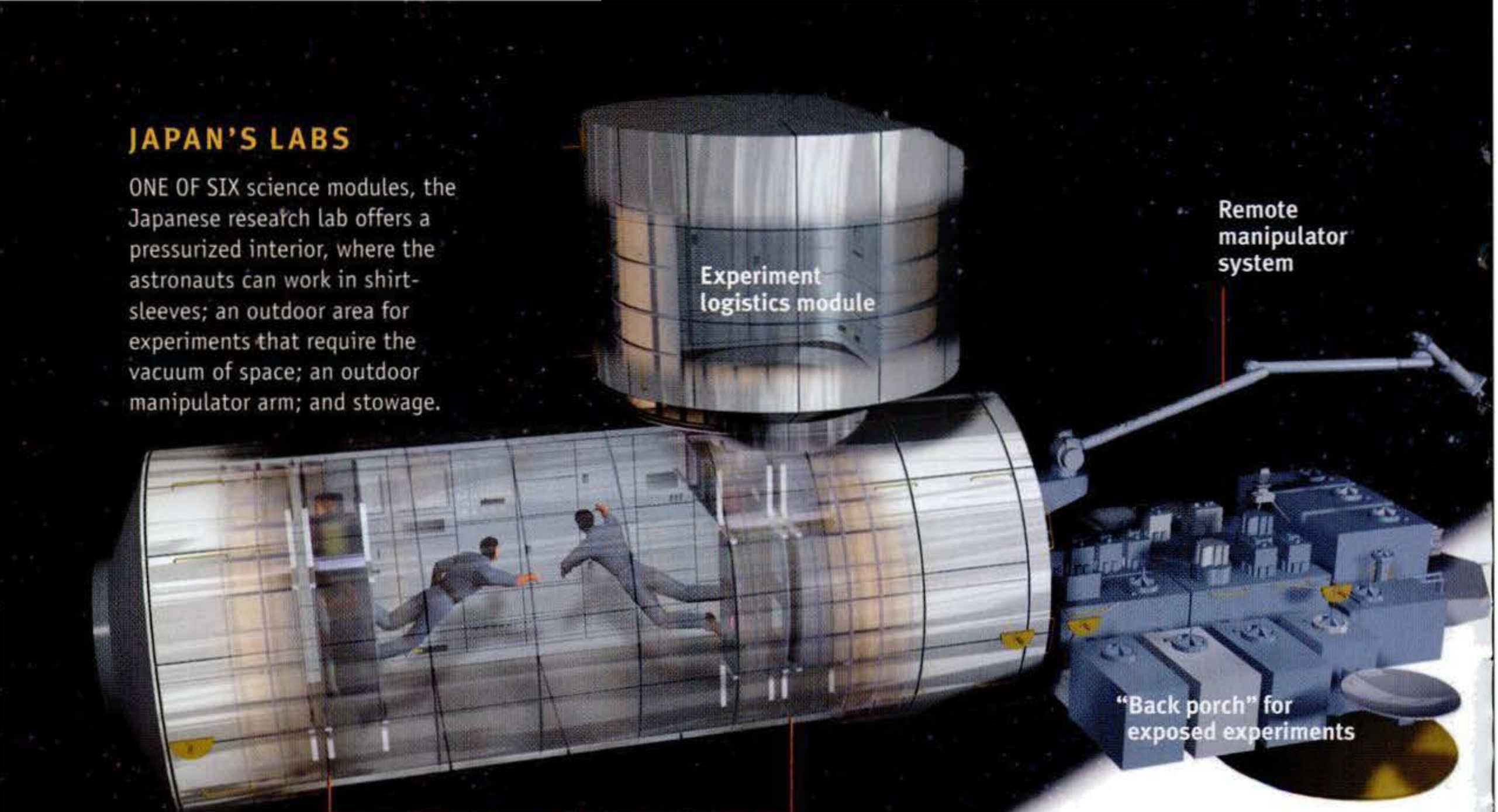
JAPAN'S LABS

ONE OF SIX science modules, the Japanese research lab offers a pressurized interior, where the astronauts can work in shirt-sleeves; an outdoor area for experiments that require the vacuum of space; an outdoor manipulator arm; and stowage.


Experiment logistics module
Remote manipulator system
"Back porch" for exposed experiments
Lab area with materials (i.e., metals) and life science (i.e., protein crystals) racks

Because there is no "down" in space, the science racks line all four walls.

ground crew would provide any last-minute adjustments or changes.

The next day, the astronaut would gather the equipment and strap it down to the nearby walls with Velcro. With one laptop's screen displaying the step-by-step instructions, he would stick his stocking feet into moveable footholds to remain fast. "If you don't restrain your feet, every time you touch the keyboard you'll push yourself away," says Bartoe, who has flown on the shuttle. "After a week, you get pretty clever just using your toes to hook onto something." A second laptop will control the experiment—the astronaut can push buttons to open valves or operate other controls. If the project is sensitive to outside contaminants, it may be placed in a "glove box." Then, the astronaut will simply stick his hands into rubber gloves reaching into the box to manipulate the experiment or handle research animals.

All of the experiments will be kept in refrigerator-size racks. Most of the racks will be dedicated to a single general discipline each, like materials science. The racks share common wiring and plumbing. Each experiment fits in a self-contained drawer—kind of like a filing cabinet—that can easily be popped out and sent back to Earth upon completion and replaced with another one.

Once the experiment is set up, the ground crew may take over monitoring so the astronaut can go on to other tasks. There'll be a link to Earth so ground-based scientists can see how their experiments are progressing and even make control adjustments to them. Once the station is manned with its full complement of six in 2002, the crew will normally spend half of its time on science.

What sorts of experiments will they do? With hundreds of researchers submitting proposals to peer-review panels, **there'll be quite a variety.** Not all are decided upon yet, but some general areas stand out.

One idea that NASA scientists bring up early in any conversation about station science is growing protein crystals. The crystals would form from solutions sent up in special containers and be returned to Earth after several weeks. Because a protein is involved in some way in every human illness, understanding these crystals can help unlock new disease therapies—and space station supporters have suggested that treatments for cancer, diabetes, AIDS, and influenza are in the offing.

In space, crystals can grow bigger and more perfectly, making it easier to analyze them with X rays to determine their structure. Understanding a protein crystal's structure is key to

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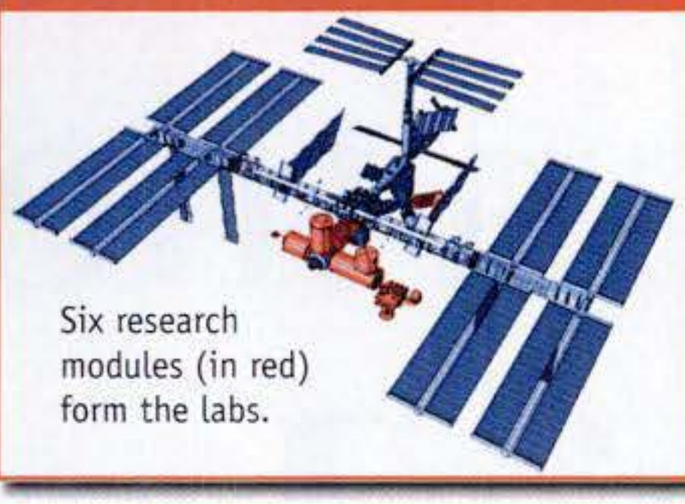
ITS PLACE IN SPACE

Astronauts will conduct research using the facilities in and outside of the station.



Six research modules (in red) form the labs.

figuring out how to thwart the disease the protein causes. "When you grow a crystal in Earth gravity, lighter material floats upward while heavier material sinks," says Lawrence DeLucas, who heads a NASA space development center at the University of Alabama at Birmingham. That can make crystals form imperfectly. But "in space, the weight doesn't exist," says DeLucas, so the molecules may have more time to arrive at the best orientation in the crystal.

DeLucas says his previous work growing crystals on shuttle missions has already helped locate the key areas of the proteins that enable influenza to spread in the body, and to design a drug to block the disease. The drug is scheduled to enter human clinical trials this summer. Nonetheless, some scientists remain skeptical about the potential of space crystals to make a big difference, arguing that Earth-grown crystals have resulted in spectacular successes, such as the family of AIDS-treatment drugs called protease inhibitors. But DeLucas remains hopeful: "There's so much potential," he says.

Scientists would also like to gain a better understanding of what happens as molten metal cools and hardens in microgravity, with the ultimate goal of creating better alloys. A special furnace facility will melt metals while instruments record the changes. "When you look at the microscopic level, you see these things called dendrites that look like Christmas trees—they're the parts that have just solidified," says Bartoe. "If the transition is too fast, dendrites can grow in a disorderly fashion. Then the metal is more brittle and of less value. Gravity works against you on Earth—hot metal rises and cool comes underneath. There's a lot of turbulent motion." However, "in microgravity, the boundary between liquid and solid is very quiet. You can see what's really going on," says Bartoe. Fast-action photography will capture the transition.

Microgravity will also help in the search for more efficient ways to burn fuel. An early station experiment will use a special breadbox-size chamber to burn a spray of fuel, similar to the way fuel is burned in automotive diesel engines and large boilers on Earth. Downlinked data will help combustion researchers understand the flame patterns, so they can develop better burners and improve space-mission fire safety.

Astronauts will not only be conducting experiments, they'll also be the subjects of study. As Bartoe puts it, "We're building a space station to learn to live and work productively in space." Space has some traumatic effects on humans—they lose bone and muscle mass, and their immune systems may also be weakened. NASA researchers are hoping the findings from the studies of astronauts will help people on Earth. Like aging earthlings, for instance, astronauts lose bone calcium—but they lose it 10 times as fast, or 1 percent of calcium each month they're in space. That's a troublesome obstacle for long-distance travel to, say, Mars. So station studies will aim to zero in on the cellular mechanisms of bone loss and how to best combat it, whether through exercise or medicines.

While the station is certain to teach us more about the human body in space, there are no guarantees about other findings. Still, basic research has often led to unexpected bonuses—what NASA chief Dan Goldin has called the serendipity of space science. Complicated, controversial projects like the Hubble Space Telescope have been proof of that. ◆

Space Research Smorgasbord

NASA PLANNERS ARE CONSIDERING an array of research areas for the space station. Here's a sampler:

- **Biotechnology** To learn more about the mechanisms of disease and how to combat them, researchers will use a spinning cylinder called a 3-D bioreactor to grow cell cultures that may be more like natural tissues.
- **Materials Science** Without gravity's influence, the underlying mechanisms that occur during the gradual solidification of molten metal could be revealed.
- **Fundamental Physics** In a project led by a Nobel prize winner, a powerful magnet will help search for particles of antimatter to gain clues about the evolution of the universe.
- **Fluid Physics** On Earth, lighter materials rise and heavier things settle. In microgravity, only atomic forces are at work. One application: understanding how soils "flow" during an earthquake, to help design safer buildings.
- **Combustion Science** Flame burns more cleanly in space. Researchers are looking for ways to burn fuels more efficiently.
- **Earth Studies** A 20-inch optical window will give instruments a station's-eye view of Earth for monitoring atmospheric gases such as the planet's protective ozone layer, trends such as reef bleaching, and events like hurricanes.
- **Life Sciences** Astronauts lose bone and muscle mass in space but regain it when they return to Earth. Researchers will look for clues for how to help solve those difficulties, which may help aging people on Earth.—*M.D.*

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A Walk on the Wild Side

Our reporter steps into an astronaut's shoes and finds them tough to fill.

By Robert Gannon

SURE, ASTRONAUTS ARE working to broach the last frontier, to seek all those scientific and engineering benefits destined to enrich life on Earth. They've got all the phrases right and say them with just the right conviction.

But when conversations with seasoned astronauts shift from the space *program* to space *walking*, you get the feeling that those ideals aren't really why they go into space after all. The true reason: It's fun.

Talk spacewalking, and something inside them goes off: Eyebrows lift. Eyes light. Voices lighten. "It's an amazing miracle," says four-time spacewalker Jerry Ross. "Every so often you stop your work, look around, and think, 'This is astonishing; I can't believe I'm here.'"

Those now in training have much to anticipate. If all goes as planned, starting in June, the building of the "station" (nobody in NASA says International Space Station or even ISS) will require an immense number of those glorious spacewalks, 75 or so. That's more than 1,100 hours—more spacewalking than in the entire history of spaceflight thus far. The work will be meticulous, dangerous, frustrating, and exhausting. But mostly, fun.

To understand, try to put yourself in the boots of a spacewalker. At Houston's Johnson Space Center, I found out that even getting into those boots isn't simple.

Over my briefs, I first slipped into snug long johns embedded with 300 feet of one-eighth-inch-thick tubing through which cooling water would flow to protect against overheating (often a bigger problem than the cold). Next, the pants: I lay on my back, wriggling, as two NASA technicians pulled them up for me—as they always do for astronauts who are on the ground. (We skipped the urine collector.) Then they neatly clamped the boots in place.

The worst part of getting into a spacesuit is struggling into the hard-shell torso section. It hung on a rack like a chest-high exoskeleton, too heavy—about 185 pounds—to manipulate. As instructed, I crouched down, not quite kneeling, and with uplifted arms, shoved myself upward, squirming, pushing with tired knees. Halfway up, feeling for armholes in the surprising blackness of a spacesuit's inside, I suddenly felt I was getting stuck. That, too—so astronaut Jim Newman had told me earlier—is standard.

The helmet plopped on quickly—but I couldn't have done it alone, either. In the zero-gravity, or zero-g, of orbit, things are easier. An astronaut dresses himself—but his fellow spacewalker is there to aid him.

In Houston, suit-up is quick, maybe 10 minutes. But in orbit, the proce-

PHOTOGRAPHED BY JOHN B. CARNETT

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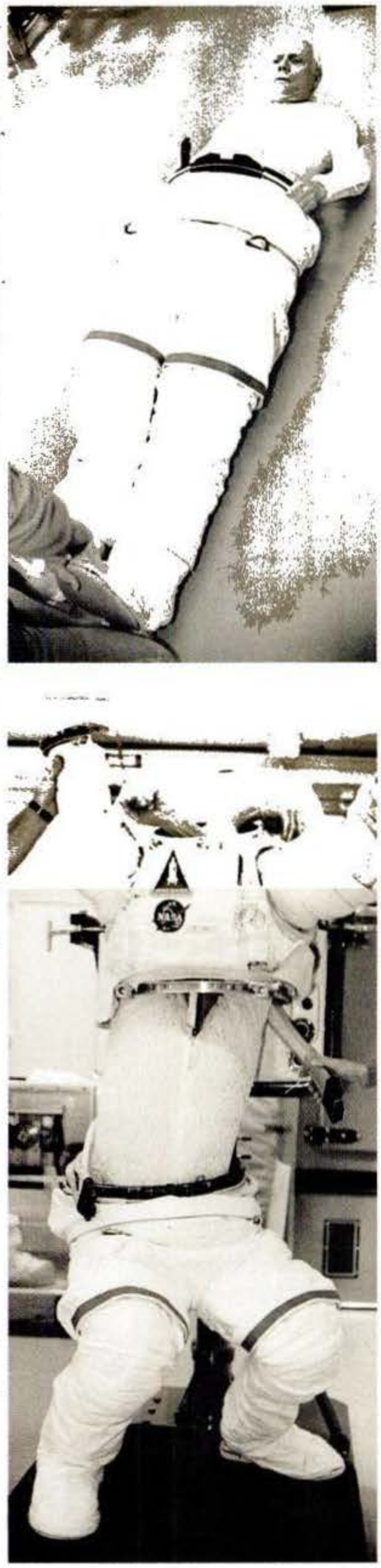

Want to walk with the astronauts? At NASA training facilities, Contributing Editor Robert Gannon learns that just getting suited up is a challenge requiring assistance: He lays down as pants and boots are put on (top). Then, he makes a squirming push into the top (above). The helmet plops on easily, but even that requires help.

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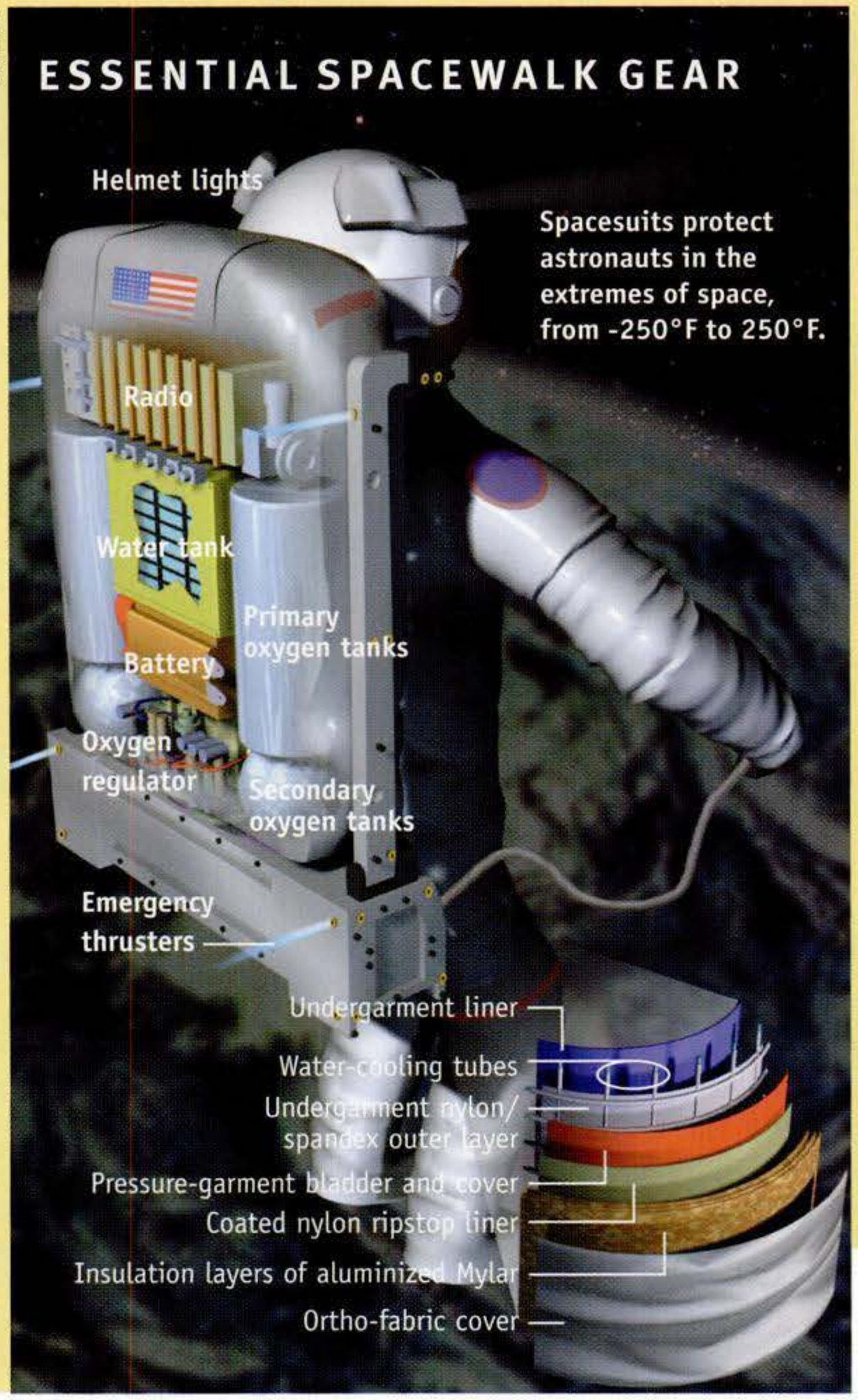
DON FOLEY

ESSENTIAL SPACEWALK GEAR



BODY RESTRAINT TETHER

MISSION: Attaches to spacesuit front and station handrails. Allows use of both hands to perform tasks.

DETAIL: Can carry replacement parts as heavy as 75 pounds while astronaut moves hand-over-hand to a work site.

PISTOL GRIP TOOL

MISSION: Has ⅜-inch drive, 25 foot-pounds of torque at 5 to 60 rpm in forward or reverse for running jackscrews in and out.

DETAIL: Programmable via 486 computer to preset torque speed and number of turns.

ROUND SCOOP

MISSION: The scoop enables space-walking astronauts to hold objects without dedicated handles. Like a cupped, grasping hand, the scoop locks onto a specific cone-shaped fitting on an object.

DETAIL: The fitting also can be grasped by the robot manipulator system.

RATCHET WRENCH

MISSION: The ⅜-inch ratchet wrench handles tasks requiring a few turns, and provides a backup for battery tools.

DETAIL: With its high-strength steel, the space wrench can support a working load up to 120 foot-pounds —almost twice that of a wrench in a home toolkit.

dure stretches to nearly an hour while the spacewalkers breathe pure oxygen (to purge blood of nitrogen to avoid the bends), drop the lock's air pressure, and consult checklists displayed on their television wristpads.

That's what it will be like when Newman and Ross—scheduled to hook up the first two station sections—get ready this July. They'll valve out the last air from the lock (feeling their suits become even more rigid), and checking once again to make sure their tethers are hooked, swing open the hatch—then out, out into the vacuum of space.

Since this won't be their first time, they won't wonder if they'll have that fear of falling. Some do; they instinctively clutch the hatch side for a moment, even voice a little "Uh!"

Newman, 42, who holds a Ph.D. in physics, last spacewalked three years ago. Ross, a 50-year-old ex-test pilot from Indiana who decided to become an astronaut in the fourth grade, last worked outside the shuttle in 1991. That's a long time to be confined inside for both of them, they say, and so once again they'll be busy absorbing it all. They'll again be astonished at the clarity, at that huge luminescent Earth stretching right there, not looking like a map at all, but actually revealing depth: Mountain ranges protrude, valleys are slashes, bands of clouds really do float along above the surface.

Which way is down? That's a rare question on Earth, but one faced by anybody in zero-g. "Some feel that wherever their feet are, that's down, even if they're walking around the walls," says Newman. "But I'm one of those who feel that what was down still is." During training, of course, mockups have floors and ceilings, "and in space, if I'm upside down in the same environment, I feel upside down."

Nothing can prepare an astronaut fully for a spacewalk, but I found that NASA's Virtual Reality Lab can help. The lab doesn't look like much—a crampy office with a garage-size stage off to the side. But when I slipped on one of the two sets of VR gloves and helmet, suddenly emerging from the lock, I was in space. That first view is so intense I momentarily got woozy; I searched for something to grab onto.

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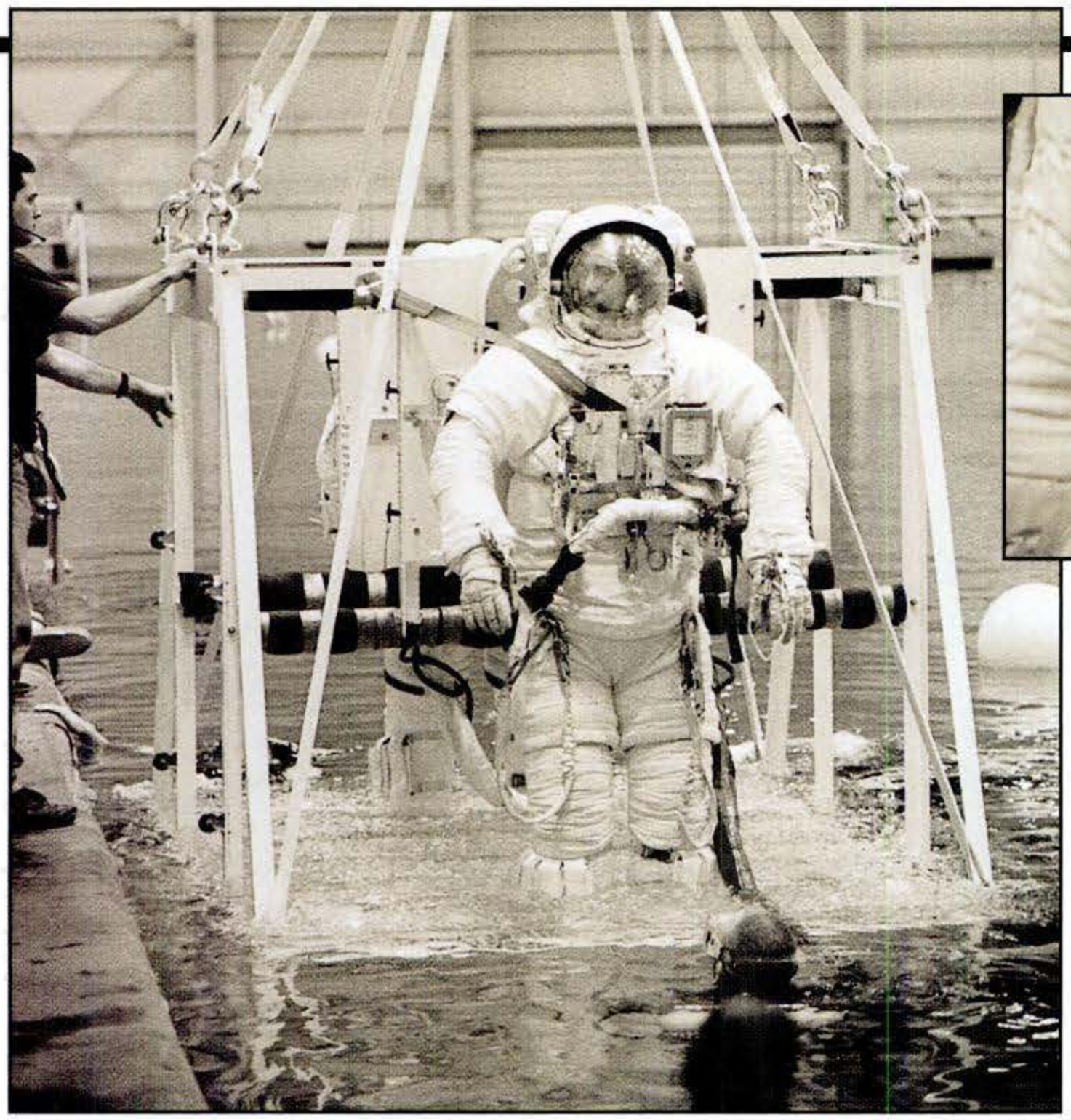


Splashdown: Left, a crane lowers astronaut Jim Newman into a giant training pool, where he'll practice spacewalks. Above, in space-suit undergarments, cooling tubes of liquid help regulate body temperatures.

I floated alongside the U.S. Node 1, and snugged up to it I saw the Russian FGB (a basic power module), just where it should be, detailed down to the handholds.

Someone with me in the lab slipped on another pair of VR gloves and helmet, and instantly I had company on my virtual spacewalk. It was fellow spacewalker Ross, a perpetual smile scanned onto his visor. (Had I been wearing the other helmet, my buddy would have been a smiling Newman.) I waved to the floating being; he saw me and waved back.

Suddenly, off to the side I caught a movement. Slipping out from behind the orbiter was Earth—immense, overpowering, dominating. Italy slid by, seemingly so close that I could have dropped a wrench on it.

In the VR lab, astronauts also learn how to handle huge weights, with the help of a silver cube, the size of an oven, that has two handhold bars in front. It's suspended in mid-air, held there by eight thin cables running from box corners to room corners. Each cable is controlled by a high-torque motor inside the cube. The box weighs about 80 pounds, but its simulated weight can be almost anything. Begloved and hooded, I tried out a simple training task: I was to pull an 835-pound plate the size of a stove top out of a rack, then hold it steady as the robotic arm I was tethered to lifted me and my parcel upward. Simple.

I reached out to grab the laboratory cube handles—but what I saw in my hood was that plate. My hand grasped its rails. I gave it a little pull. It seemed oddly resistant, so I gave it a healthy jerk. It came out all right—and kept on coming, nearly knocking me right off my stool.

What happened was that in the simulated zero-g of space, I subconsciously judged the box to weigh 25 pounds or so. But the computer, controlling those eight motors, was calculating 835 pounds. I wasn't allowing for mass.

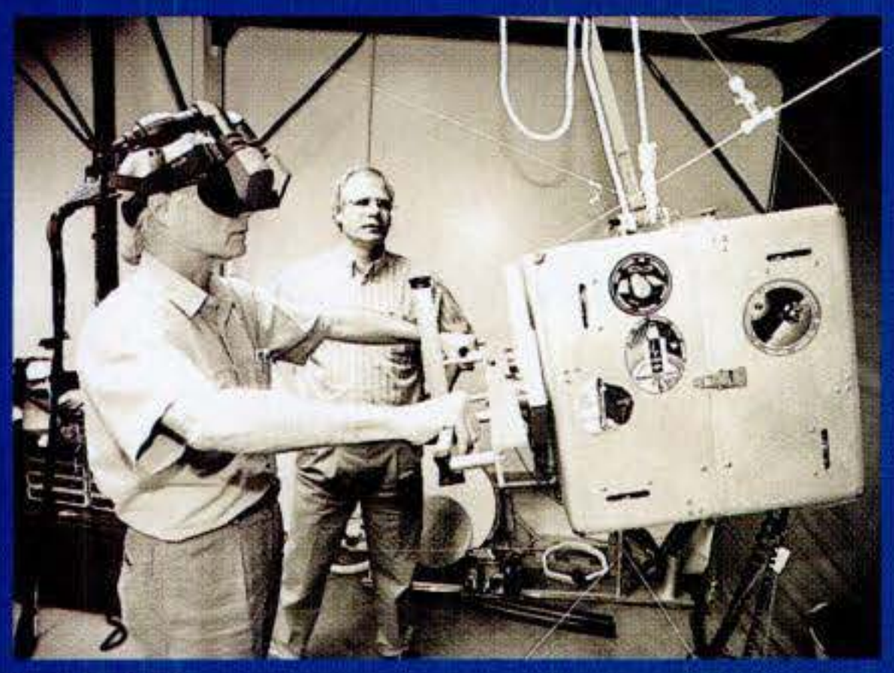
Holding the plate steady as my virtual platform rose was even odder. The plate and I lifted slowly, and even though I was holding it at its edge (impossible on Earth), it weighed nothing. But the helmet tickled my ear, and when I let go with one hand to scratch, the plate got off balance; my wrist wasn't strong enough to hold it level. Even though I quickly grabbed it with the other hand, it started oscillating, wider and wider.

Suddenly I got the idea. I successfully learned to damp it. Caught it just before it flipped off into space.

While astronauts say that the VR feeling of floating is very real, irritants

Virtually in Space

BEGLOVED AND HOODED, writer Robert Gannon lifts equipment during a virtual spacewalk.



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Hands-On Designs

DON'T LET mechanical engineer Amy Ross start in about space gloves. She'll talk about the palm plate and the dual gimbal, the metacarpal joint and the bladder convolutes, and . . . well . . . you get the idea.

Space gloves must be protective—yet flexible enough for delicate tasks.

Ross has a special interest in the International Space Station: Her father, Jerry Ross, will be bolting the first two sections together. In her office, reaching toward space, rest two of his molded hands, and her job is to glove them in something protective, comfortable, and usable.

Not an easy task. In NASA's spacesuit lab I tried the Glove Box. It's a plastic cube with two holes through which gloves are inserted for testing. Pump out the air until it's 4.3 pounds per square inch below ambient pressure (the suit pressure on spacewalks), and the elbow-length gloves balloon. I slipped my arms into the gloves, then tried to work with an oversize socket wrench. I felt like a lobster—and these are the best space gloves in the world.

Trouble is, space gloves must insulate (down to -455°F), resist damage (to cut them with a knife you have to saw), fit well, and even provide heat (by fingertip elements).

After 15 minutes, my fingers were tired and cramping and frustration was putting me in a rotten mood. My hands, I learned, are simply out of shape.—*R.G.*

still often appear in space that don't show up on Earth. "There's a place right under my left shoulder blade that gets bruised every time I'm in orbit," says Ross. "I fit into the suit differently without gravity."

And in space, astronauts have concerns—fleeting as they are—that they don't have on Earth. "One time I just happened to realize that the suit I was wearing is not real thick," recalls Newman. "If a micrometeorite comes by at just the wrong time and pops you, you're toast. But then I thought, 'Nobody's been popped yet.'

"And here's another," continues Newman, "a question both my wife and my mother asked before my first flight: What happens if the tether breaks? Easy. On [pre-station flights], the commander could simply move the shuttle over to you. Now things are even easier—we have Safer." That's an emergency pack with jets that a drifting crew member could use to blow himself safely back home.

Spacewalking astronauts also think about accidentally ripping the suit—but it's tough, and the station's surface should have no sharp edges. If a suit does get punctured, an emergency oxygen supply can be tapped that will keep it inflated for 30 minutes even with a eighth-inch hole.

One incentive for avoiding spacesuit leaks is sharply brought home by a demonstration shown to crew members when, still dressed in their spacesuits, they rest in a Houston vacuum chamber while air is pumped out. "There's a cup of water sitting there on the floor," recalls Newman. "The boiling temperature, you know, keeps dropping as the air pressure drops. When it reaches 0.6 pounds per square inch, the boiling point and freezing point merge. The water in the cup suddenly bubbles, boils very rapidly, and then *crack*, it freezes. At 0.6 psi, blood will do the same."

STARS OF THE STATION

WILLIAM SHEPHERD

BORN: July 26, 1949
HOME: Oak Ridge, Tenn.
ROLE: Shepherd and two crew members will fly on a Soyuz rocket in January 1999. As the ISS commander, he will be first aboard the station.

NASA

JAMES NEWMAN

BORN: October 16, 1956
HOME: San Diego, Calif.
ROLE: A crew member on the first shuttle mission to assemble the station, Newman will spacewalk to connect the first two sections.

JOHN B. CARNETT

To rehearse the choreography of the first construction mission, and to help sidestep problems, spacewalkers practice day after day in what NASA calls the Neutral Buoyancy Lab. The work of that first mission is to hook Node 1 to the Russian FGB. The orbiter will shove them together in the same way the shuttle docks to Mir. The maneuver is challenging, but the true drudgery comes during the three 6-hour spacewalks when the workers will first attach such things as foot restraints, tether guides, and handrails, then the critical fluid lines and electrical cables. Hauling those cables around and hooking up scores of connectors is especially rough work, meticulous and tiring. Cables can entangle, pins can bend, fittings can break.

The Neutral Buoyancy Lab is one of the biggest swimming pools in the world—a hundred feet across and twice as long, its 40-foot depth is large enough to hold major station sections. The building containing it is so huge it looks empty, even though at least a hundred technicians are attending to the needs of just two will-be spacewalkers.

Ross is there, built like a quarterback, looking as solid as a post in blue booties. So is Newman, tall and graceful in his tubey long johns.

Trussed to an iron platform, they're dressed by their attendants. Then, because they can't walk in those spacesuits without falling down, a crane plucks up the whole works and gently lowers it into the water. Newman tries an awkward little wave just before his faceplate submerges.

Underwater, they're more mobile, but still act like arthritic walruses as they wire and bolt and assemble components on a detailed mockup of the first two station sections. Here too they have attendants, hovering like pilot fish, tugboating them from one site to another. Swimming by themselves is pitiful.

For each of the three spacewalks, they must practice the 6-hour routine underwater 10 times. That's a total of at least 30 days. You'd think they'd eventually get sick of it.

But everyone agrees, pool training is superb. "I've seen beginners completely exhaust themselves in a half hour," says Ross. "They're fighting to make the suit do things that it's not capable of, and they haven't learned how to finesse themselves around in the water—moving too fast, trying to maintain orientation, failing to tether themselves to counteract the forces they're applying."

Adds Newman: "In the pool you have to fight the viscosity and the gravity. When you go head down, your shoulders are resting against the neck ring—that's what's holding you up—and the blood rushes to your head. Not pleasant. Things are easier in orbit. Water work is like training for a marathon with leg weights."

Up near the building's ceiling, the operation control room offers a wonderful overlook of the pool and its contents. But nobody looks out those picture windows. They all stare at the nine TV screens, at scenes from cameras carried by swimmers, and they listen to underwater conversations.

"Well, this is pretty real," I hear Ross say. "I'm upside down and backward, and I just broke another connector."

Then Newman: "Where are the handholds here?"

Someone topside: "What? They're not fastened on yet?"

"Nope."

"I asked for them three weeks ago. I'll order them again." (In space, ordering is more difficult.)

Astronauts worry about such things, items forgotten, holes unaligned, fasteners bent. It's inevitable. Newman tells the story of his first flight, when a $\frac{5}{8}$-inch wrench failed to fit a $\frac{5}{8}$-inch nut. The wrench had been beautifully designed, machined to perfection. "But after fabrication, they painted it. Changed its size."

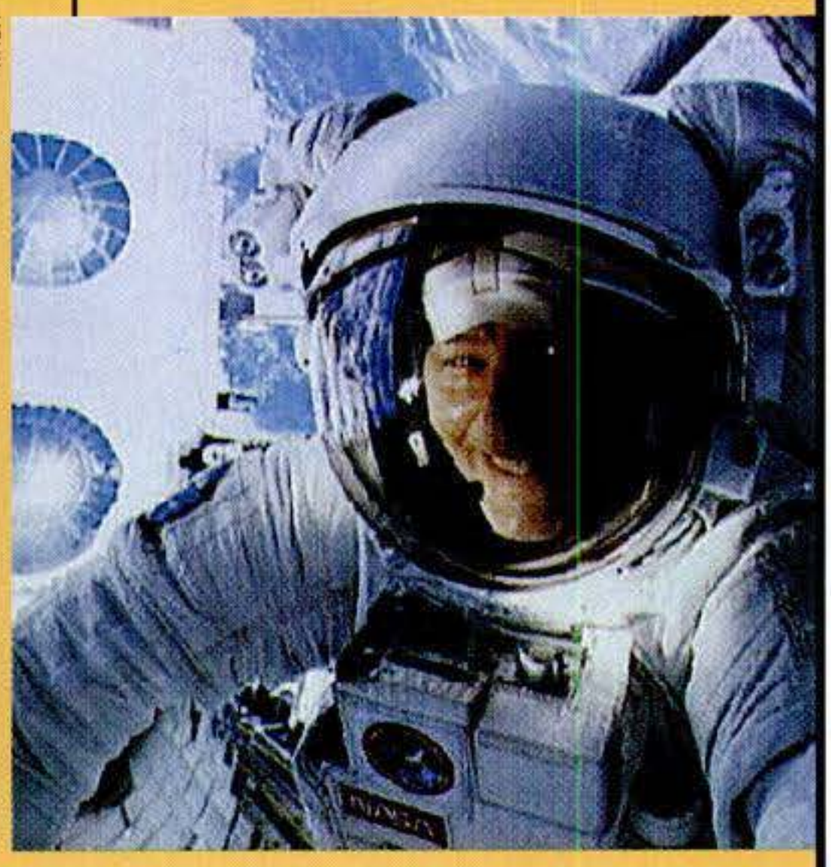
As for me, after my brush with spacewalking equipment, I'd have another worry, and I don't think I'd make it even if they'd have me. I don't see how I could go a full workday without blowing my nose or scratching my ear. ◆

BARBARA MORGAN

BORN: **November 28, 1951**
HOME: **Fresno, Calif.**
ROLE: Originally a backup for Christa McAuliffe, Morgan, a teacher, could fly as early as the summer of 2000.

JERRY ROSS

BORN: **January 20, 1948**
HOME: **Babylon, N.Y.**
ROLE: With 850 hours in space, Ross is NASA's most veteran astronaut. He will spacewalk with Newman on the first assembly mission.



NASA

Interview with Barbara Morgan www.popsci.com

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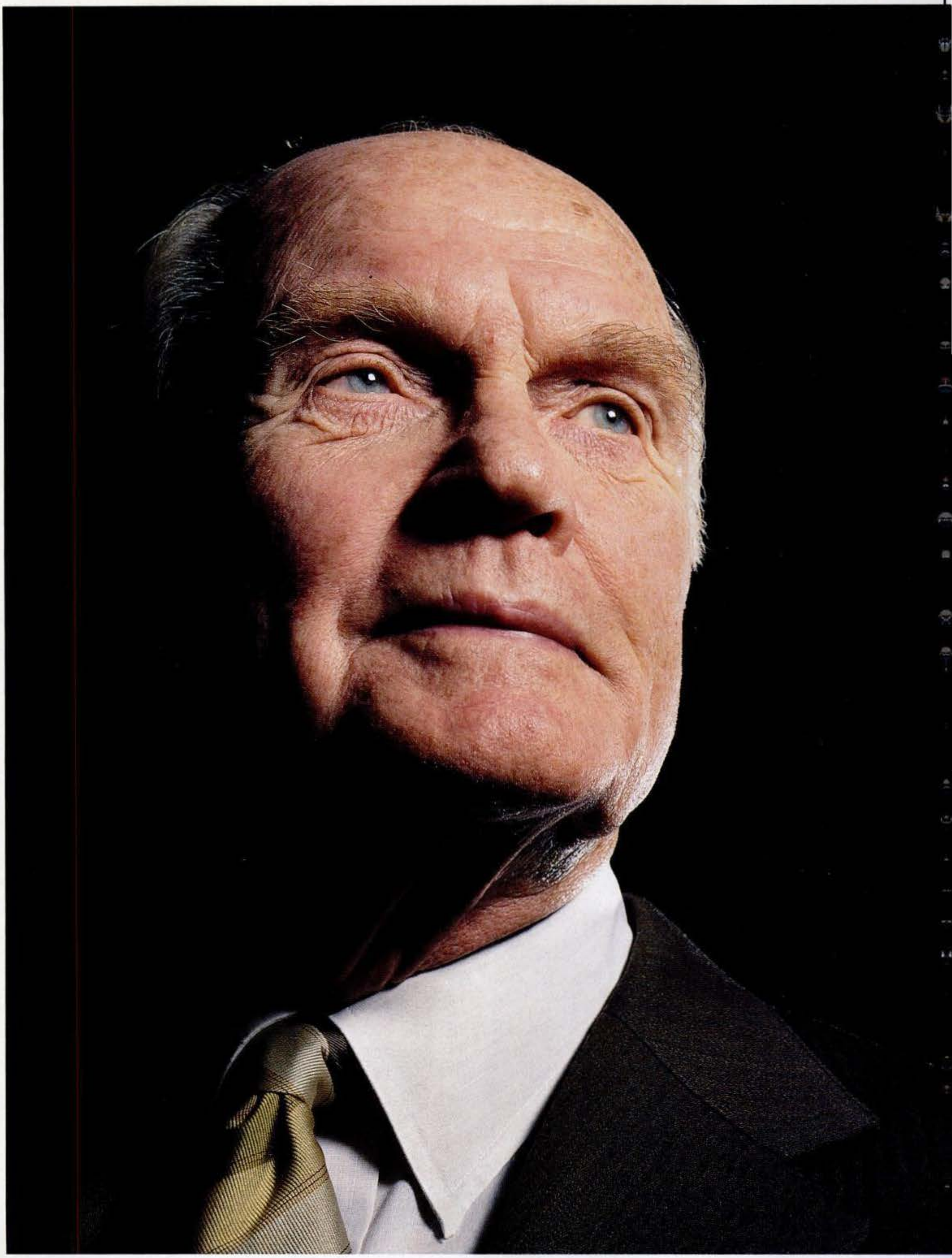

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The Right Stuff—Again

John Glenn, the first American in orbit, could pave the way for civilians in space.

By Jim Schefter

"GODSPEED, JOHN GLENN." SCOTT CARPENTER'S VOICE on the comm loop echoed into history 4 seconds before the Atlas rocket engines ignited into orange-white flame. A moment later, the first American to orbit Earth was on his way, climbing through the mid-morning Florida sky.

It was 1962. The risks of spaceflight were mostly unknown, the dangers fierce and real, and a handful of gutsy men, on the ground and above it, ran the race of their lives to win the high frontier.

"People have forgotten that it was a race," John Glenn says today. "The Soviets were ahead of us and they were making a lot of hay, claiming the superiority of communism, selling their ideas to underdeveloped countries around the world."

It was up to the original seven astronauts, selected in 1959, to play the role of both test pilot and test subject.

"There were a lot of questions about human capacity in space," Glenn says. "Doctors even thought that the human eyeball would change shape in weightlessness and we wouldn't see clearly."

Glenn answered many of those questions in his three-orbit, 4-hour 55-minute Project Mercury mission, which included an eye chart he could read perfectly. He was 41.

Now he will have the chance to answer new questions when he rides the space shuttle Discovery for 10 days in late October. He will be 77, and will become the oldest human ever to hurtle beyond the bonds of this planet.

There is some controversy over this flight—the cynic's view is that it is a play to Congress and a nostalgic public for more money for NASA. But others see Glenn as being in the vanguard of paving the way for regular folks to spend time in space.

Glenn first left Earth as a test pilot and Marine colonel. He

The once and future astronaut: John Glenn is getting ready to blast back into orbit aboard the shuttle this October.

PHOTOGRAPHED BY JOHN B. CARNETT

John Glenn pauses during Mercury-Atlas 6 mission training in February 1962 at Cape Canaveral, Florida.

NASA

returned to be covered in glory, and was considered such a national treasure that President John F. Kennedy quietly passed the word that he should not be risked in space again. When Glenn periodically asked Robert Gilruth, director of the Manned Spacecraft Center in Houston, for a place on a two-man Gemini crew, he was gently rebuffed. "Headquarters isn't ready for that just yet," Gilruth would say.

"I finally got the message," Glenn says. He retired from the Marines and, in 1974, won election to the U.S. Senate from Ohio. He will be retiring from that distinguished career at the end of this year.

But first, there's another trip into low Earth orbit.

"Who would have thought that age would be an advantage in getting back into space?" Glenn muses. But that was how he convinced NASA, with the backing of researchers who want to know how an old body reacts to zero-gravity, that this was a trip worth taking.

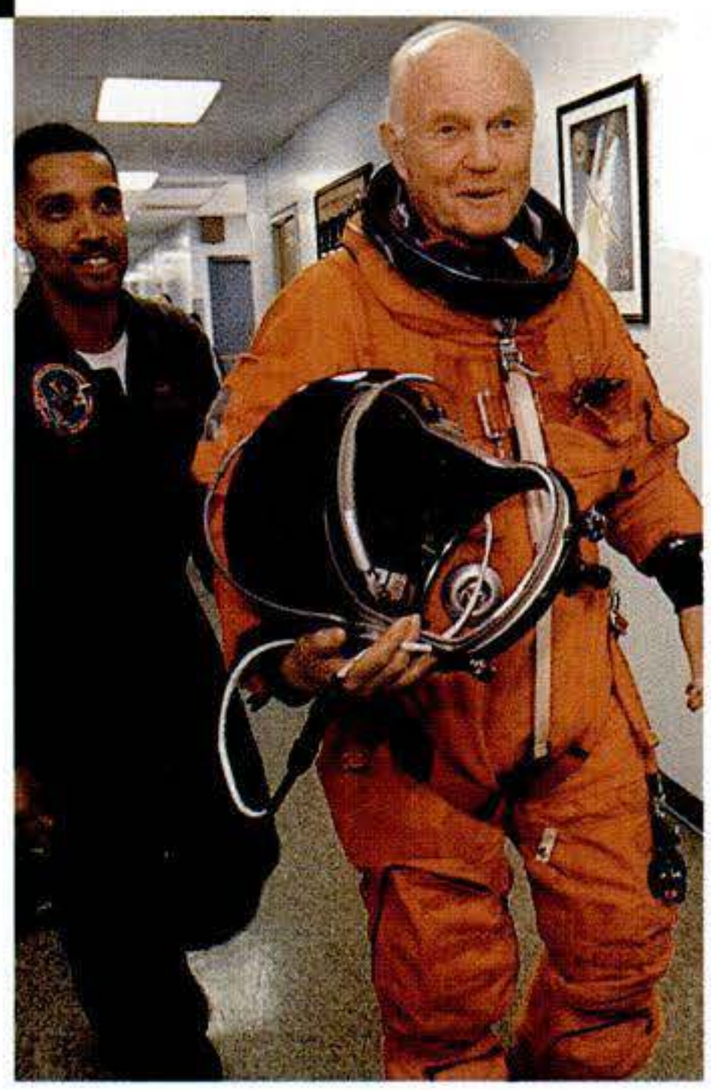
Compared with Mercury, the shuttle is roomy and its environment is benign. Astronauts pull no more than 3 gs (three times the force of Earth's gravity) during launch and reentry, and that only briefly.

"My Mercury capsule would fit into a corner of the shuttle payload bay," Glenn says, chuckling. "And the most I could do in my flight was loosen the straps that held me in."

He endured and suffered much more in training for Mercury than he will to prepare for his new mission. Sessions on a centrifuge remain painfully bright in his memory.

"Al [Shepard] and Gordo [Cooper] and I ran up to 16 gs," Glenn says with a grimace, "and that's a gut-buster. You even think about relaxing and every corpuscle wants to give up."

When someone decided that a worst-case reentry scenario would have the Mercury capsule landing in high winds, then tumbling end over end, the doctors sent Shepard and Glenn back to the centrifuge. "They had us doing tumble-runs," Glenn says. "We called them e-i-e-o—eyeballs in, eyeballs out." Both astronauts had shoulder-strap bruises on their bodies. But they passed every test.



AP PHOTO/ KIN MAN HUI, POOL

Sen. John Glenn heads to the centrifuge area at Brooks Air Force Base in Texas this February. The centrifuge helps ready astronauts for the forces experienced during shuttle launch.

Then the medics worried about an astronaut's ability to recover if his craft spun out of control in orbit. They devised a rig with multiple gimbals and six degrees of freedom. Glenn sat suspended in the center with a hand controller that fired air jets. First they'd tumble him in one axis. He'd read the instruments, then recover with the controller. Then they did two axes, then made it all three—pitch, roll, and yaw—in a wild multidimensional gyration at as many as 30 rpm.

"I was going tail over teakettle," Glenn says, "but I showed them that an astronaut could regain control."

So primitive was the Mercury capsule, and still so unsure of how an astronaut would manage in space were the flight surgeons, that there was to be no camera onboard when Glenn flew. Messing with a camera would be too distracting, they said.

"I went in to Bob Gilruth and said 'For heaven's sake, I'm not going to get so carried away with the camera that I'm not going to monitor the things I'm supposed to be monitoring,' and he agreed," Glenn recalls.

Engineers built a hand grip on a Leica 35mm so Glenn could both snap pictures and advance the film one-handed while wearing a glove. It didn't work quite right. Then a few weeks before he flew, Glenn went to Cocoa Beach, Florida, for a haircut and stopped at a drug store.

"I saw a Minolta Hi-Matic camera for $45," he recalls. "It was one of the first cameras with an automatic winder. I bought it on the spot."

That camera went into orbit with John Glenn, and his one-handed photos of a bright and radiant Earth below were published around the world. Cameras became standard spacecraft equipment from then on.

Now Glenn, still lean and fit, is eager to show that a healthy 77-year-old can handle whatever modern spaceflight has to offer. The race this time is with age. But the words at liftoff should be the same.

"Godspeed, John Glenn." ◆

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Mission Detail

Checklist: Software, robot camera, atomic clock, shuttles, and a strategy for descent.

IT'S OFTEN THE LITTLE things that make a trip go smoothly or prove to be the most memorable. Certainly, the space station makes use of a few special items not found in your typical travel kit. And here's a grab bag of simulations for those of us left behind who want to share the experience.

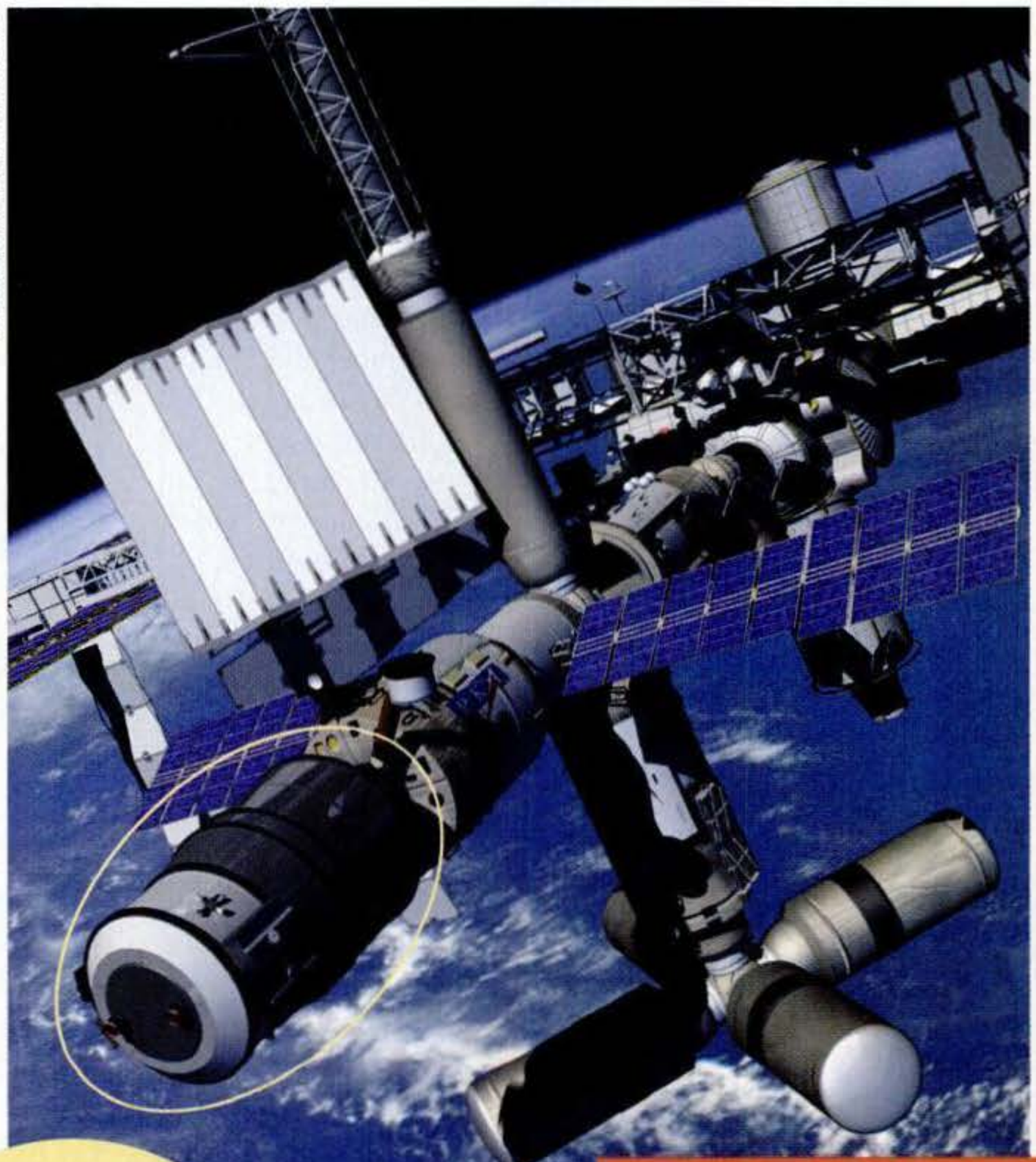
Getting Down

SOMEDAY, THE International Space Station will descend, but if you're frightened at the prospect of a million-pound hunk of metal falling out of the sky, take heart. NASA does have a plan to decommission the space station eventually without creating havoc.

The European Space Agency is planning to build three expendable space vehicles by 2003: two of them will ferry propellant, the other will force the station to land in a designated area. Called an automated transfer vehicle (ATV), the craft will be unmanned, similar to the Russian Progress resupply vehicle but larger, with enough thrust to nudge the entire station down in a single piece—a cheaper and safer alternative to hauling pieces of the station down in multiple trips.

Roughly 90 percent of the station will be cinder by the time it reaches Earth's atmosphere; a Pacific splashdown is the plan.—*Gunjan Sinha*

BOB SAULS/JOHN FRASSANITO & ASSOCIATES



ITS PLACE IN SPACE

With an ATV, the station's landing can be narrowed to a 500- by 30-mile area of the Pacific.

The ATV will be used to help bring ISS out of orbit.

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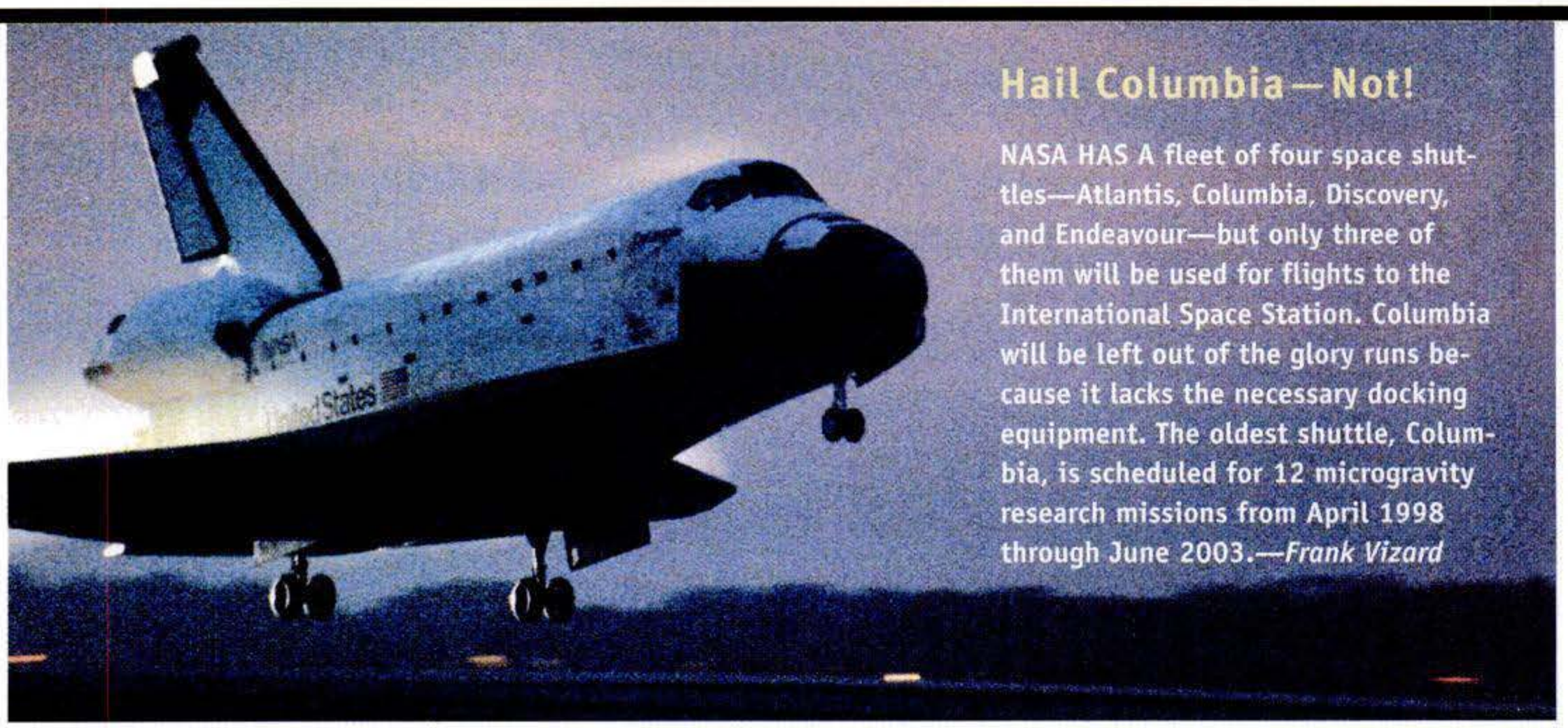


Hail Columbia—Not!

NASA HAS A fleet of four space shuttles—Atlantis, Columbia, Discovery, and Endeavour—but only three of them will be used for flights to the International Space Station. Columbia will be left out of the glory runs because it lacks the necessary docking equipment. The oldest shuttle, Columbia, is scheduled for 12 microgravity research missions from April 1998 through June 2003.—*Frank Vizard*

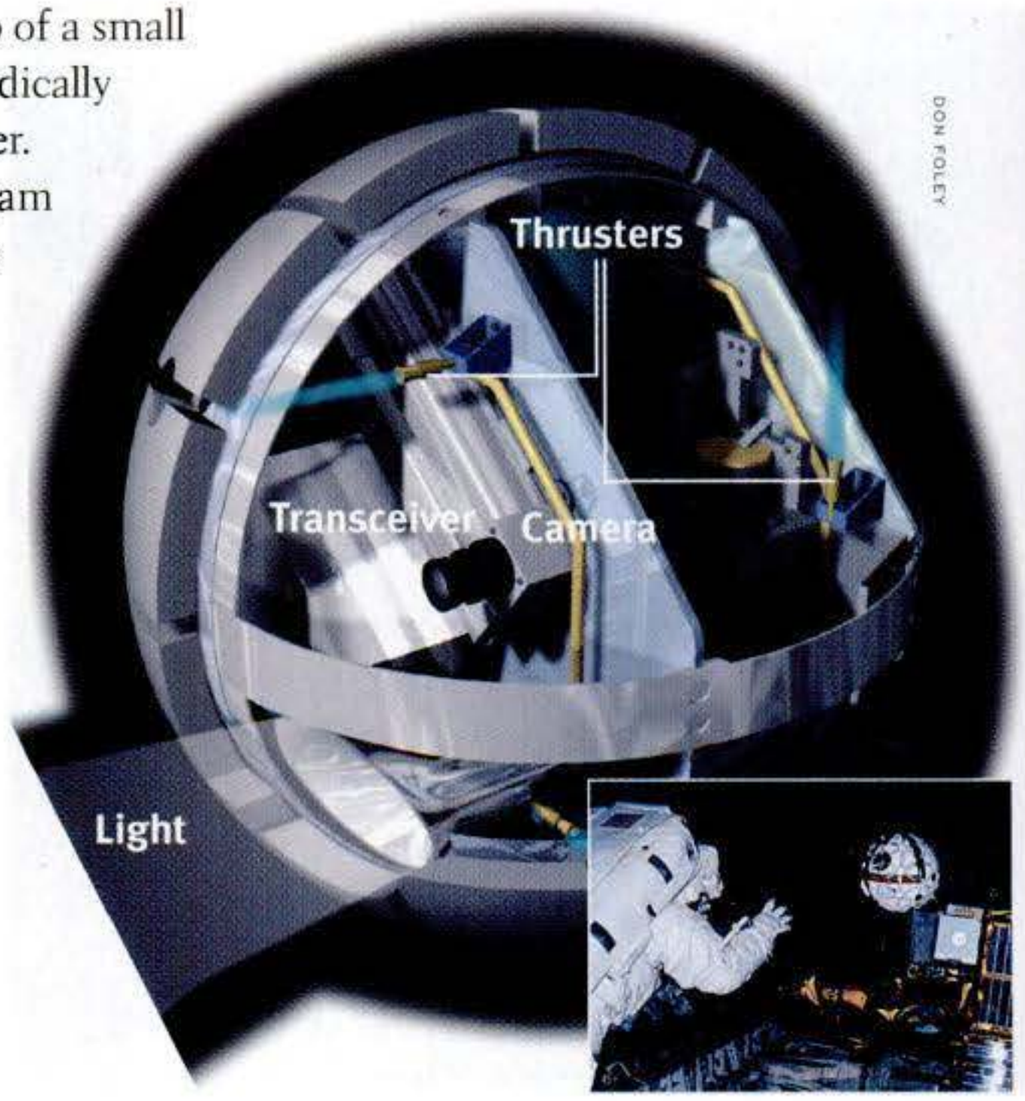
Danger Zone

NASA ESTIMATES the odds of a fatal accident similar to that which befell the Challenger space shuttle at 1 in 145. By contrast, the chances of disaster aboard a commercial jet airliner are estimated at 1 in 2 million.—*F.V.*

Robot Inspector

A VISUAL inspection of the exterior of the International Space Station is a little more complicated and time-consuming than a walk around the family car. Making such inspections quicker and easier is the job of a small robotic craft that will periodically give the station the once-over.

The beachball-size Aercam (Autonomous EVA Robotic Camera) was successfully demonstrated on the STS-87 shuttle mission last December, flying 150 feet in 10 seconds. The 35-pound 14-inch-diameter craft consists of batteries, a compressed nitrogen container, 12 very small thrusters, two video cameras, a spotlight, radios, and a computer. The Aercam has soft covering to prevent damage if it accidentally collides with an astronaut or another object in the shuttle's cargo bay.



DON FOLEY

Once aboard the space station, Aercam will operate autonomously and be capable of recharging itself. At predesignated times, Aercam will inspect solar arrays for damage from micrometeoroids and debris. It will fly over the arrays and use its camera to inspect each solar cell. If a cell's appearance has changed, an astronaut will be notified to look at the video and decide what to do. Other sensors could search for chemical leaks, unwanted vibrations, or other potential problems.—*Philip Chien*

Flying SuperGuppy

SPACE STATION components will have been in flight before the ISS gets into space, because the SuperGuppy is handling the delivery of the pieces to the launch pad. The special cargo plane made by Aero Spacelines of California has a hinged nose that makes loading and unloading large pieces of equipment easy. An earlier version was used as far back as the Gemini and Skylab programs.—*F.V.*

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Window on the World

WHEN ASTRONAUTS feel homesick, they can get a gorgeous view of Earth through a high-quality optical window. The Earth-facing window will incorporate the highest-quality optical glass ever used in a crewed spacecraft.

It's not all for looks, either. By 2000, a rack above the 20-inch-diameter round window called the Window Observational Research Facility (or WORF) will accommodate sensors, cameras, and other instruments for Earth-science studies. Even earthbound kids will get to use the window: Through a program called EarthKAM (for Knowledge Acquired by Middle schools), students will be able to remotely request images that they can use for school projects. The rack will include stowage area for the equipment.

After the station is completed, an updated power distribution unit from Brazil will enable more than one instrument to operate at the window at a single time.

The window is fashioned from fused silica made by Corning.

BOB SAULS/JOHN FRASSANITO & ASSOCIATES

Unlike the soda lime glass used in home windows, which has a greenish tinge from iron, fused silica glass is crystal clear and free of impurities. The window is also polished very flat—over any 6 inches of its diameter, the surface variation is less than 63 nanometers, or billionths of a meter.—*Mariette DiChristina*

Being An Astronaut Makes Little Cents

GOING INTO ORBIT isn't exactly a get-rich-quick scheme for Americans. U.S. astronauts on active military duty get their military pay and benefits, but the pay checks will hardly make them wealthy.

Technically, an astronaut in space is a civil service employee on official travel and entitled to an expense allowance. But because the government provides the transportation, living quarters, food, and clothing, it deducts these costs. What's left amounts to an "incidentals" bonus of about $2 per day, or roughly 1 cent for every 200 miles in space. Shannon Lucid's record-setting 188 days in space aboard Russia's Mir netted her a "bonus" of $376.

Russian cosmonauts, by contrast, get $1,000 bonuses for spacewalks and other hazardous activities performed in space, often returning to Earth very wealthy by Russian standards.—*P.C.*

Time Finally Flies

CESIUM ATOMIC clocks are now the gold standard of timepieces. The accuracy of today's most advanced model, the NIST-7 (designed and operated by the Department of Commerce's National Institute of Standards and Technology), equates to gaining or losing a second in 6 million years. That fantastic accuracy derives from the measurable vibrations of the cesium atom: 9,192,631,770 per second.

Remarkable as this is, it can be improved—in space. Gravity on Earth limits how long each cesium atom can be observed. In the microgravity of space, each atom can be observed for several seconds. That's why an advanced laser-cooled cesium clock will be placed on the International Space Station. Laser beams "freeze" the atoms in place, which adds to the long-term stability of the clock. The net effect, NIST scientists predict, is that the space clock will be at least 10 times as accurate as its Earth-bound brethren.

LAURENT CILLUFFO

The clock will help solve some fundamental physics questions relating to relativity. One is whether the speed of light is really the same in all directions. The clock will also refine the accuracy of Global Positioning System readings, sharpen the definition of a second, and enhance our ability to synchronize clocks on Earth.

The clock is scheduled to be ready to fly in five to seven years. The Jet Propulsion Laboratory will make it space-ready.—*Arthur Fisher*

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Space at Mock Speed

WANT TO GET a little hands-on experience with the International Space Station? Here are a few ways to learn more:

• If you're traveling in Florida, the Kennedy Space Center provides a unique opportunity for you to view, from an elevated area, each space station module as it's readied for its trip into orbit. On exhibit are full-size mock-ups of the habitation and laboratory module, which houses the science labs, and Node 1, a connection piece that allows astronauts to move between space station modules.

• Sarex (*www.ccsds.org/sarex*), a program that currently lets students talk to astronauts aboard the shuttle via ham radios, will extend that capability to space station astronauts.

• Create your own space station on your computer with the Skybase CD-ROM from Piranha Interactive Publishing of Tempe, Arizona. The $30 Windows 95 CD-ROM lets you build and tour the currently planned version of the station. Learn about living conditions 220 miles above Earth, and follow planned module launches from Internet sites as they happen.—*Suzanne Kantra Kirschner*

PIRANHA INTERACTIVE PUBLISHING

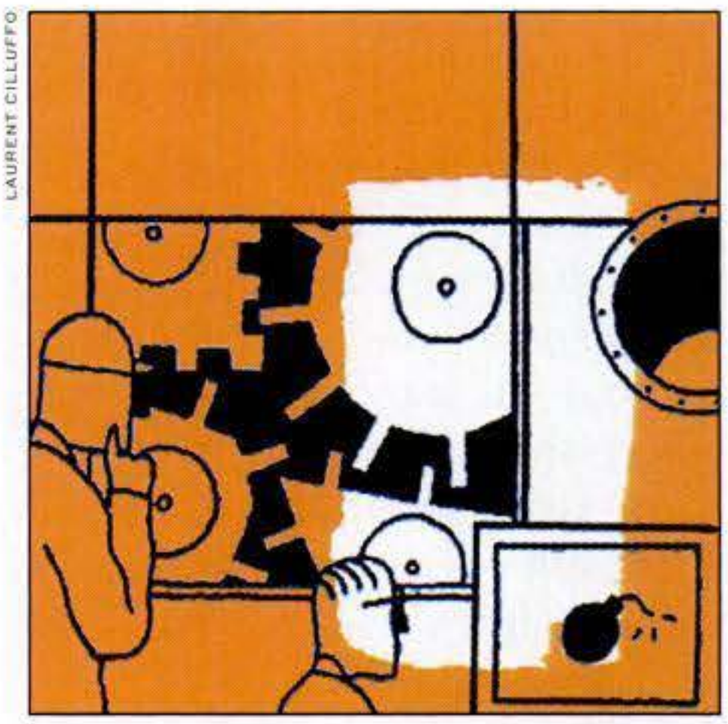
Spaceware 1.0

FOR ALL OF THE physical science needed to get the space station assembled and into orbit, computers may be what keeps it up and running smoothly—or not. Computers will control everything from vital navigation and life-support systems to earthbound e-mail messages.

The massive undertaking is made all the more complex by the fact that the software, always the trickiest part of any computer system, is being developed by four separate U.S. teams, with Russian, Italian, and Japanese contributions. The U.S. portions alone add up to more than 3 million lines of code (written in Ada, long the preferred programming language of the Department of Defense), according to Joe Sherrill, command and control software manager for Boeing in Houston. Getting all the pieces tested and integrated as a cohesive whole is the ultimate challenge.

To make troubleshooting easier, the software that runs the trio of computer networks aboard the space station is written to operate in synchronous, or serial, fashion rather than the faster but more complex asynchronous. Fortunately, software behaves exactly the same in microgravity as it does on terra firma. "We have the ability to simulate on the ground exactly what we expect to see in space," notes Sherrill.

In the event of a hardware hiccup, the software will use a backup computer. The radiation-shielded



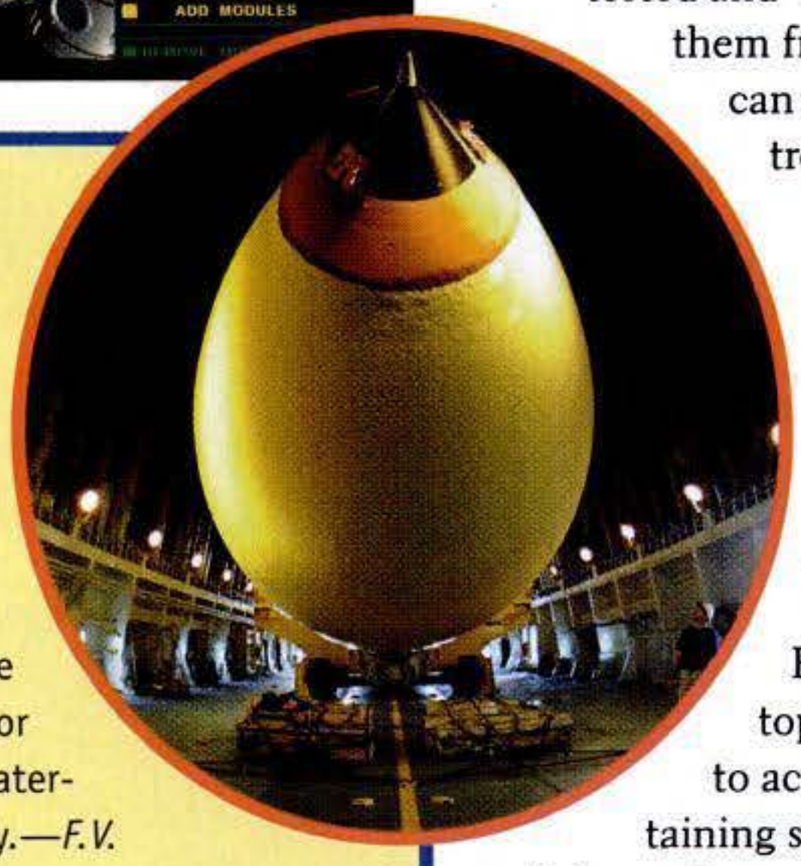
LAURENT CILLUFFO

computers are Honeywell-built PCs running Intel 386 microprocessors—yes, 386s—remnants of the Freedom project preceding the International Space Station. Sherrill claims the extra power of a modern Pentium-class computer isn't needed. Furthermore, the 386s have already been space-tested and "hardened" to protect them from radiation that can easily damage electronic gear.

The space station crew will use more modern laptop computers running Windows 95, frills included, for e-mail and other activities via a wireless RF network. The laptops will also be used to access CD-ROMs containing station maintenance information.—*Chris O'Malley*

Better Booster

ONE KEY TO getting space station elements into orbit faster is a new external fuel tank for the space shuttle being used for the first time aboard flight STS-91, scheduled for this month. While the tank containing liquid oxygen and liquid hydrogen appears identical to its predecessors, it is actually 7,500 pounds lighter. This means the shuttle payload will increase by the same amount. While the interior has been redesigned, the major change is the use of a lightweight aluminum-lithium material even stronger than the metal alloy employed previously.—*F.V.*



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What the Patch Means

Blue represents the planet Earth.

The five-pointed stars represent the space agencies of the United States, Russia, Europe, Japan, and Canada.

The chain symbolizes the thousands of people all over the world who helped build the station.

Stars and planets in deep space are goals yet to be achieved.

The laurel stands for peace.

The overall crucible shape is the container the ISS will fill with knowledge.

Space Soda

THE CASH-poor Russians have been by necessity exploiting commercial opportunities presented by their presence aboard Mir. Now it seems NASA has caught on. Coca-Cola, for example,

has already flown two soda machines, each costing $95,000 to build, aboard the space shuttles to see if they will dispense cold soda in space. Both missions were a success, and Coke is now negotiating to get aboard the space station. Still, visitors to the ISS may not know what to ask for—NASA calls a soda machine a "fluid generic bioprocessing apparatus." Presumably, it's still the real thing. Now, how about a burger and some fries?—*F.V.*

Orbital Time

SPACE-traveling requires precise timing, so just any old watch won't do. Worn by both the Mir crew and shuttle astronauts, the Speedmaster Professional X-33 from Omega is the arms-on favorite of the spacey set. Naturally, there is a countdown mode, and it lights up in the dark. A Mission Time chronograph displays elapsed time in days, hours, minutes, and seconds so you know exactly how long you've been in space. Astronauts insisted on a 80 dB alarm so they could hear it above the background din. (Who knew a spacecraft was so noisy?) The X-33 comes with a choice of a titanium bracelet ($2,995) or a bulletproof Kevlar strap ($2,595) that protects against hostile fire from alien life forms, if they show up.—*F.V.*

Name That Station

1984 President Reagan orders NASA to build $8 billion space station called Freedom by 1992.
1993 Redesign yields versions named Alpha, Beta, and Charlie.
1993 Alpha plus Russia equals Ralpha. Cutbacks shorten name to Ralph.
1993 NASA submits Alliance, Alpha, Aurora, Sigma, and Unity names to White House.
1995 No decision yet. International Space Station moniker comes into use.
1998 ISS delegates meet in Montreal to discuss name issue. No decision.

Backyard Views

WANT TO EYEBALL ISS in space? Get up early or stay up late. Be ready to squint and don't blink. When the space station is finally pieced together, the 100-meter-long winged colossus will be one of the brightest stars in the night sky. Moving as fast as a satellite, the space station will appear no bigger than a dot to the naked eye. But through binoculars, it will look slightly larger, roughly the same size as the planet Jupiter. During the day, you might be able to catch a glimpse of it by using special filters or a telescope.

The best times to view the station, however, will be slightly before sunrise or sunset. The station will be closest to Earth at these times, but you'll be able to see the station only when it passes within a radius of about 620 miles from your location. NASA will post a schedule of viewing opportunities at *www.nasa.gov.* Viewing opportunities may only be a few seconds in duration.—G.S.

Space-related software www.popsci.com

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Teamwork.

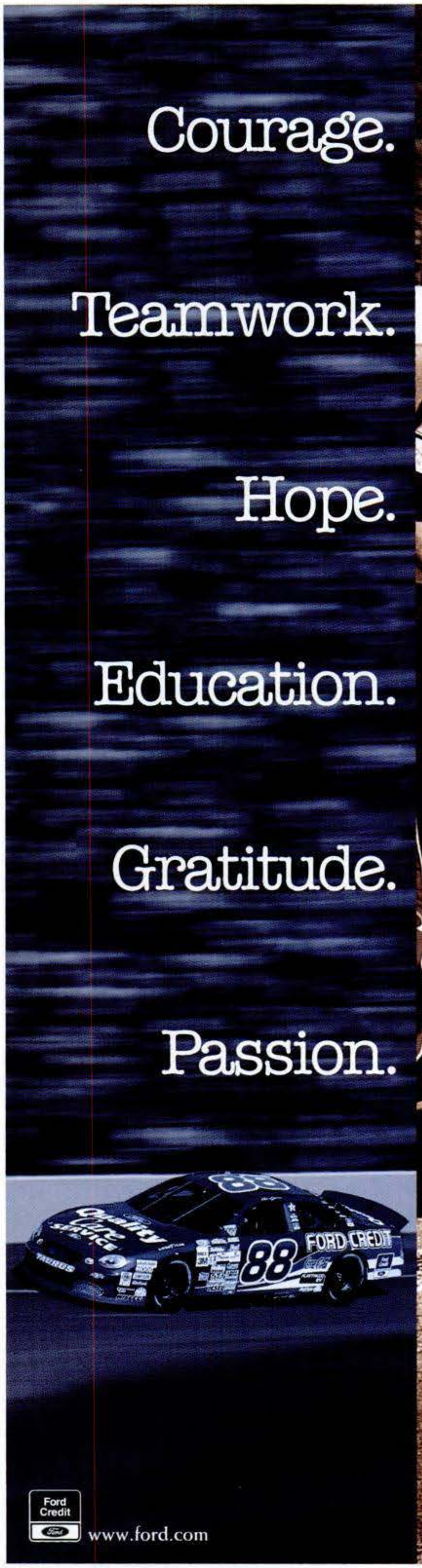
Hope.

Education.

Gratitude.

Passion.

All in 16.84 seconds.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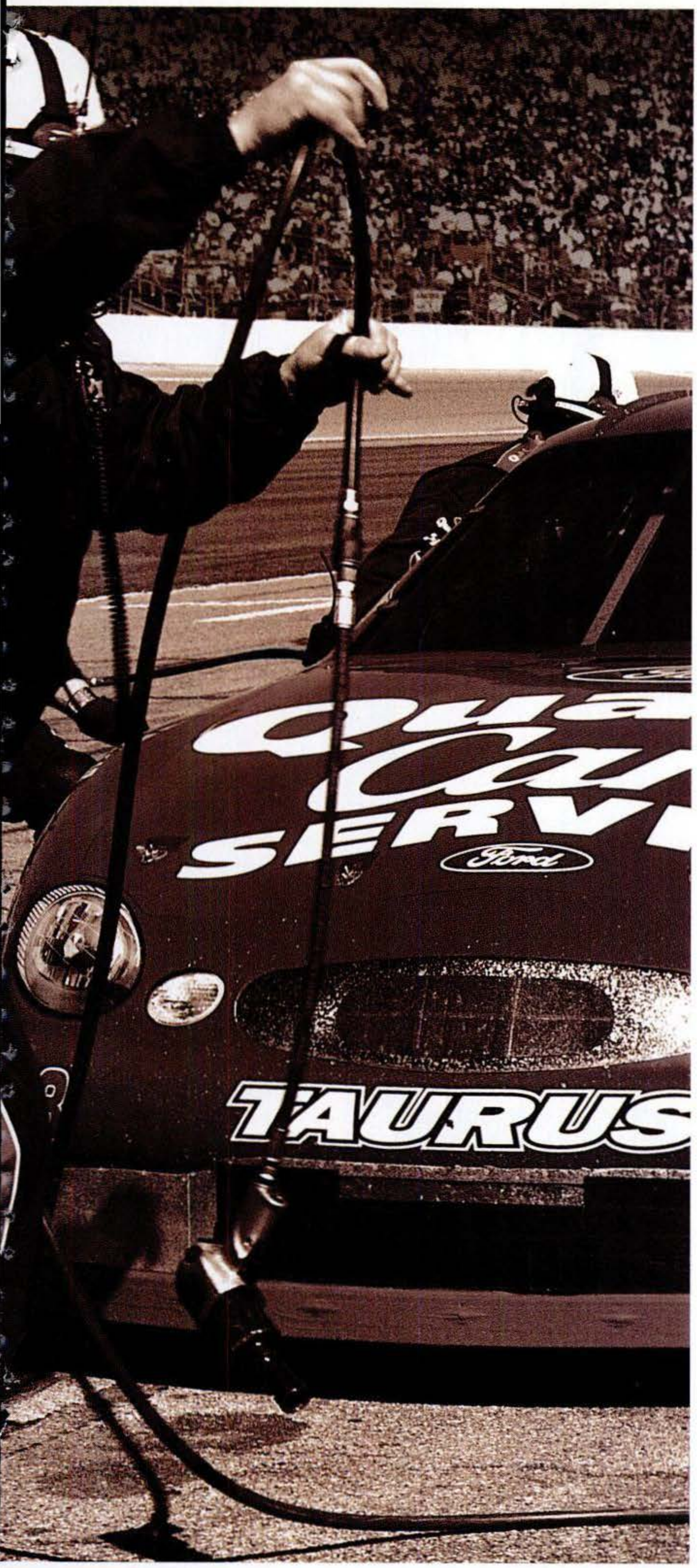

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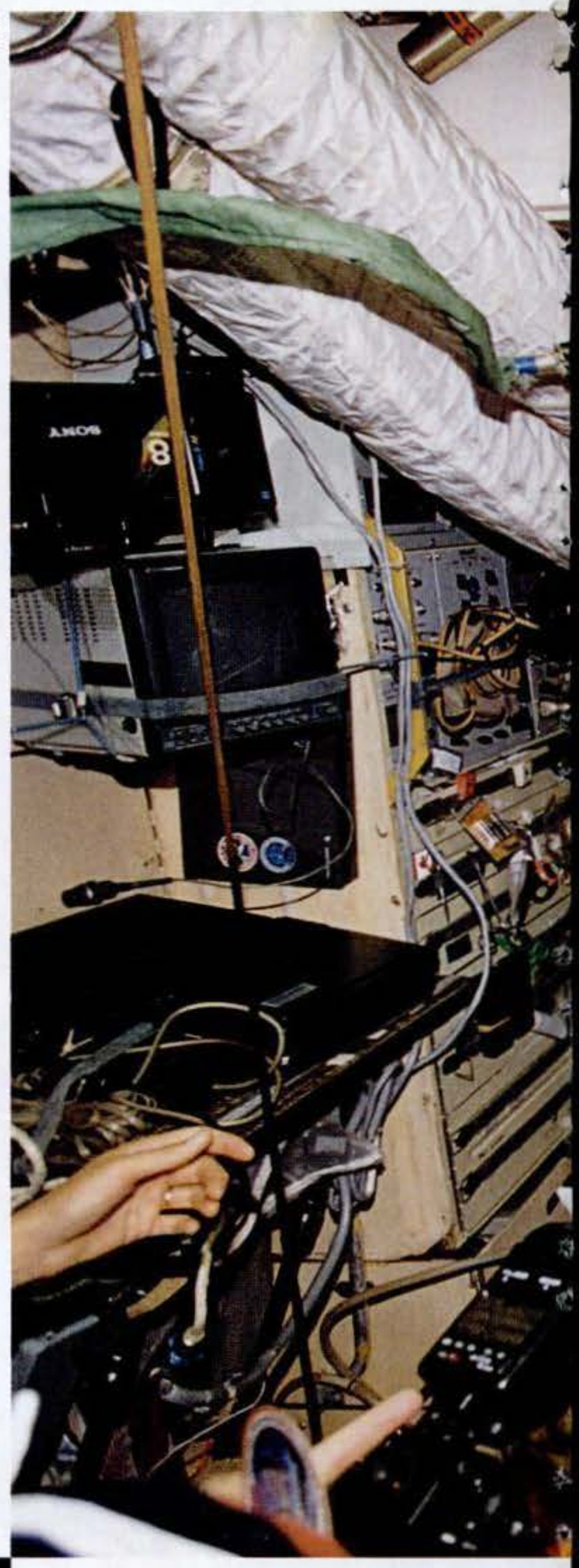
Space Jalopy

Mir proves the perfect training ground for extended missions to space, because things go wrong all the time.



NASA

By Philip Chien

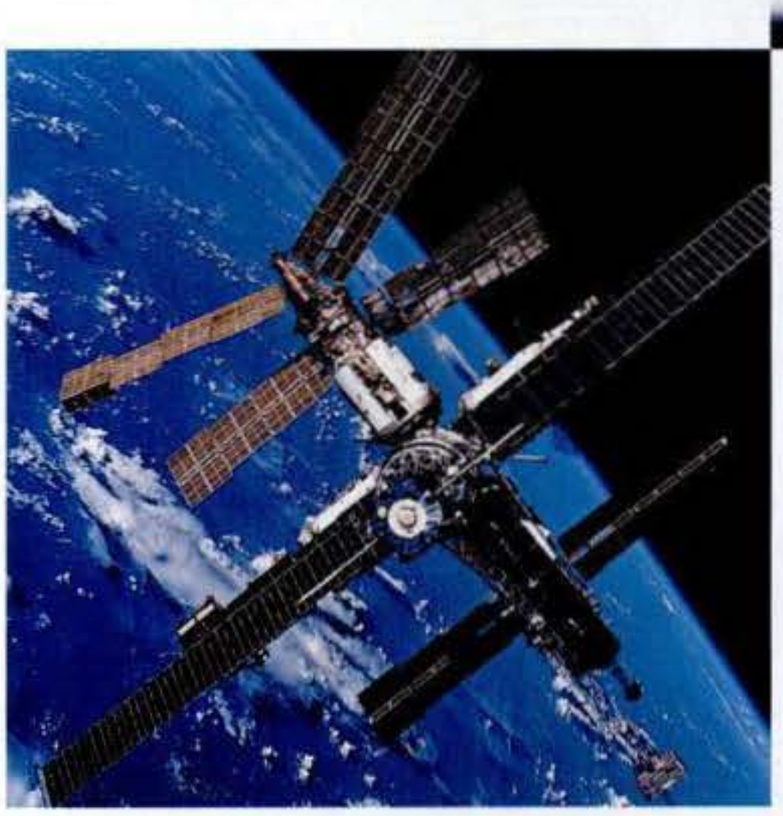
IF YOU'VE EVER FELT LIKE your world was about to come crashing in around you, then imagine how the six spacefarers on Mir orbiting 236 miles above the Atlantic Ocean felt when a fire suddenly threatened to bring their mission and perhaps their lives to a tragic end. The Russian-built Mir space station already had been in orbit for 11 years, and Americans had been rotating through for the past 14 months. Up until the February 23, 1997, fire, Mir had experienced its share of problems, but they hadn't been life-threatening.

"*Seryozny!* (It's serious!)" shouts a Russian voice as the alarm sounds. An oxygen generator is spewing flames, and since it contains its own fuel and oxygen supply, there is no way to put the fire out. Mir commander Valeri Korzun aims a fire extinguisher at the wall behind the fire, hoping to keep the hull's temperature below its melting point. As one fire extinguisher is exhausted, American astronaut Jerry Linenger hands Korzun another.

"We had a good flame on Mir," recalls Linenger. "Probably a 2-foot flame, molten metal flying from that for another 2 or 3 feet—kind of a sparkler effect."

The fire is so dangerous that the six-person crew may have to evacuate Mir. The flames, however, block the way to one of the two three-person Soyuz spacecraft that would be used to escape. Crew members start to wet down blankets that might afford some protection if they have to leap through the flames.

Fortunately, the oxygen generator chooses that moment to burn itself out. The oxygen gen-



NASA

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No place for claustrophobics or neat freaks, Mir is a jumble of ducts, wires, conduits, electronic gear, and cramped humanity. In the midst of apparent chaos, crew members have performed research and livesaving emergency repairs.

erator, generally considered to be a very reliable device, is believed to have had a contaminated seal, which sparked the emergency.

An unusual day in space? Not exactly. Last June 25, cosmonaut Vasily Tsibliev was testing the procedure for docking a Russian Progress freighter manually. The remotely controlled Progress was approaching much faster than expected. Tsibliev fired braking jets to slow Progress down, but to no avail. Progress collided with Mir, but fortunately struck a noncritical area, the Spektr module, so lives were not immediately in jeopardy. Nonetheless, the crew could hear the hiss of air slowly leaking out into space.

The slow change in air pressure allowed for an orderly but rapid shutdown of the impacted area. Astronaut Mike Foale shut off the computers in Spektr and unplugged the electrical connectors that brought power from the solar array to the rest of Mir. The remaining lines that passed through the hatch were severed with a cable cutter. A blank hatch was put over the Spektr module to seal it off. During the shutdown, 15 percent of the atmosphere had been lost.

Repairs were eventually performed and power restored, but these emergencies and a host of others, about 1,500 large and small, aboard Mir are now entries in the lesson plan being

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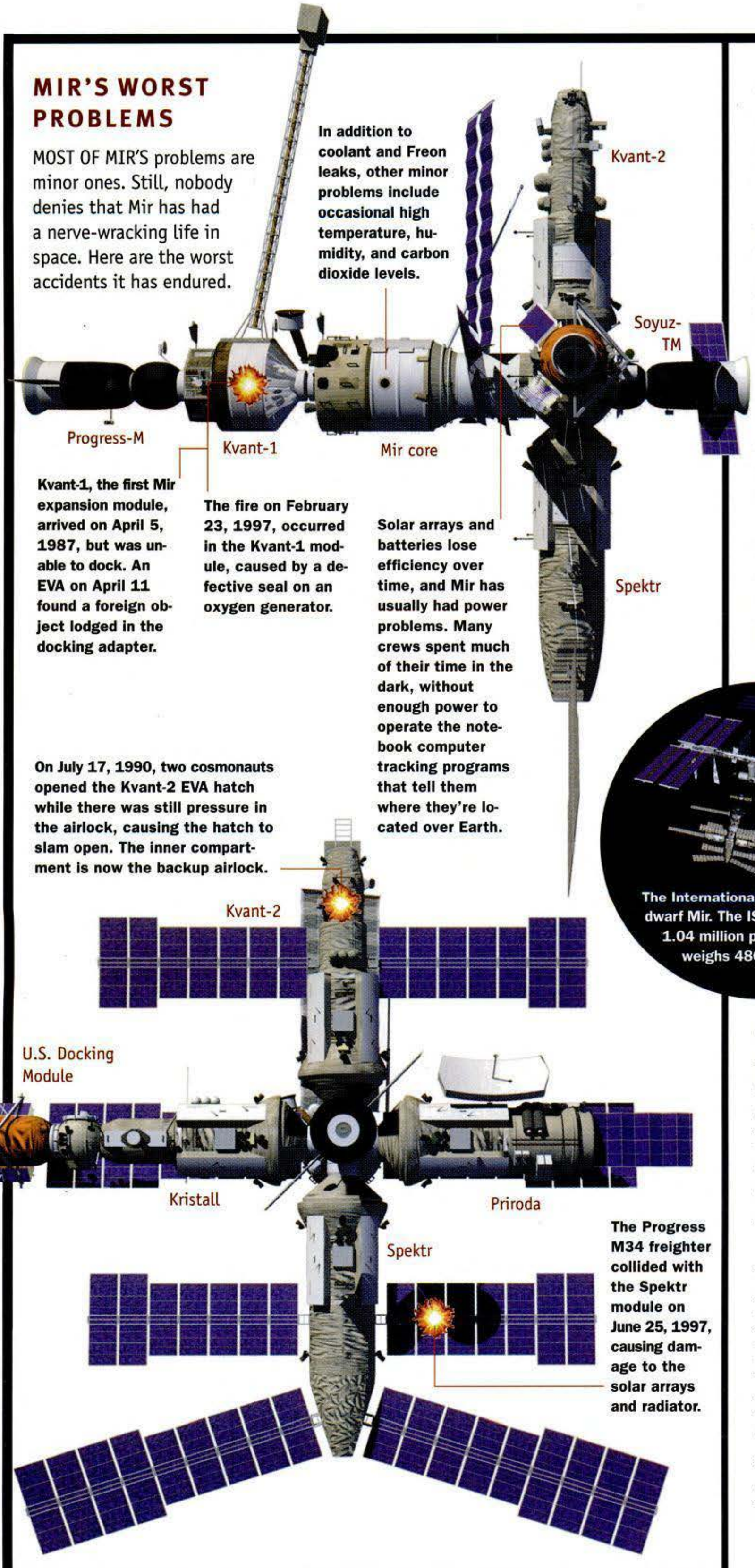
MIR'S WORST PROBLEMS

MOST OF MIR'S problems are minor ones. Still, nobody denies that Mir has had a nerve-wracking life in space. Here are the worst accidents it has endured.



In addition to coolant and Freon leaks, other minor problems include occasional high temperature, humidity, and carbon dioxide levels.

Kvant-1, the first Mir expansion module, arrived on April 5, 1987, but was unable to dock. An EVA on April 11 found a foreign object lodged in the docking adapter.

The fire on February 23, 1997, occurred in the Kvant-1 module, caused by a defective seal on an oxygen generator.

Solar arrays and batteries lose efficiency over time, and Mir has usually had power problems. Many crews spent much of their time in the dark, without enough power to operate the notebook computer tracking programs that tell them where they're located over Earth.

On July 17, 1990, two cosmonauts opened the Kvant-2 EVA hatch while there was still pressure in the airlock, causing the hatch to slam open. The inner compartment is now the backup airlock.

The International Space Station will dwarf Mir. The ISS will weigh about 1.04 million pounds, while Mir weighs 480,680 pounds.

The Progress M34 freighter collided with the Spektr module on June 25, 1997, causing damage to the solar arrays and radiator.

written for the International Space Station. Mir, in fact, has been the U.S. training ground for the International Space Station project.

By this month, seven U.S. astronauts will have logged 31 months aboard Mir, with 28 months of continuous occupancy dating from March 1996. By contrast, it took 12 years and 60 shuttle flights for U.S. astronauts to achieve one accumulated year in space. Astronaut Shannon Lucid set the record for women in space at 188 days while cosmonaut Valeri Polyakov holds the record for men at 679 days, 438 of which were consecutive.

Mir, which translates from the Russian as "peace" or "small autonomous community," is the laboratory in which the survival manual for the space station is being written. NASA, in fact, considers the Mir/shuttle program to be Phase 1 in the development of the station.

This month, the space shuttle Discovery makes the last flight to Mir. What lessons have researchers learned from Phase 1? The fire and the collision were the two most dramatic mishaps to occur on Mir. After the fire, software for the ISS was modified so that a single command can stop ventilation between modules, halting the spread of smoke. The Mir collision prompted the development of a new proximity sensor that more accurately measures distances.

Not every lesson learned from Mir was the result of an emergency, and the mission has been far from a failure. Mir's core module was launched in February 1986, and Mir was expected to have a lifetime of only five years. Mir is now the oldest spacecraft in orbit, and its surface is covered with small dings from meteorites and space debris. Inside, the electronics have been periodically exposed to radiation,

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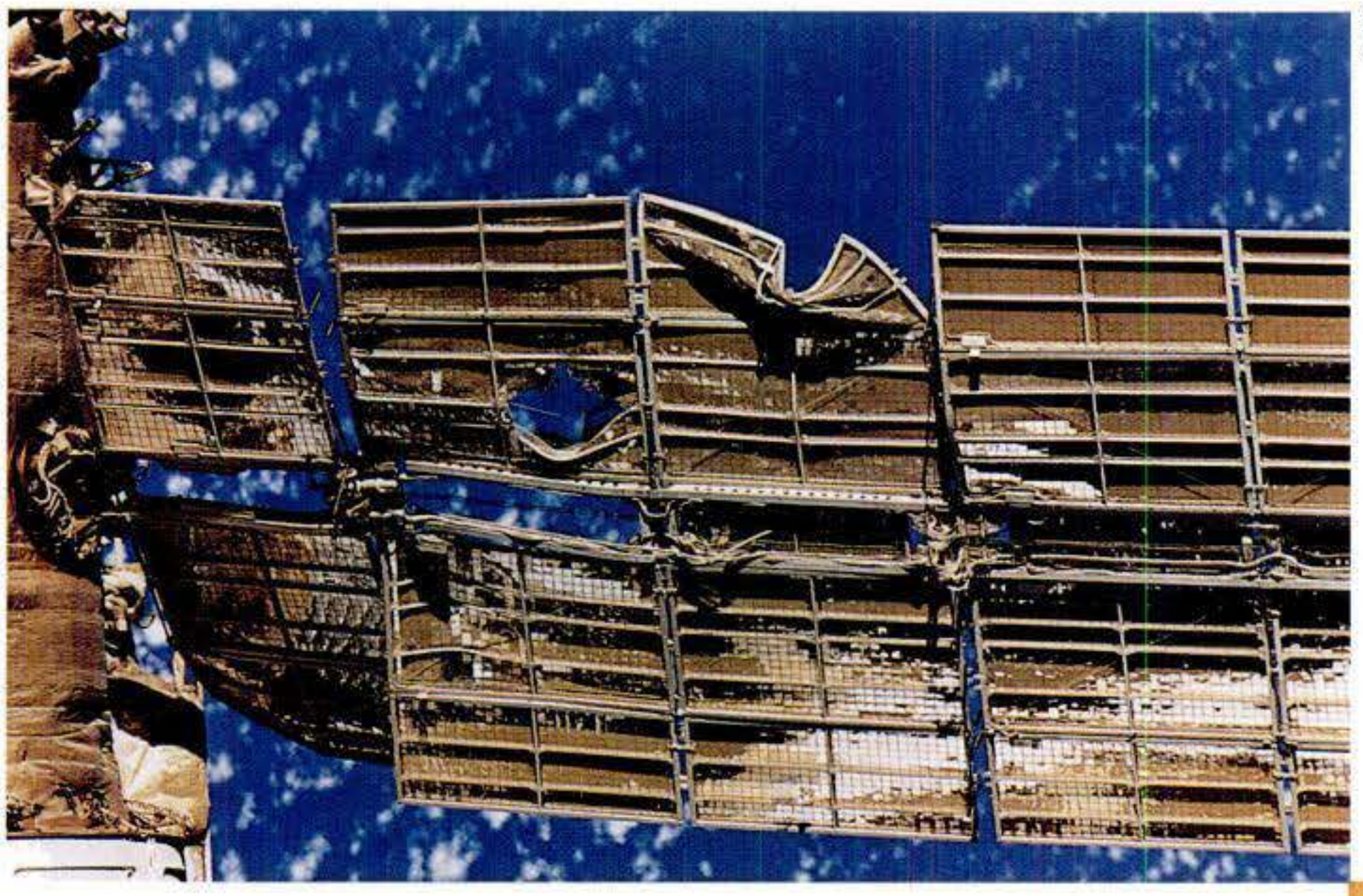

NASA

Damage to Mir's solar arrays reflects the impact of a Progress supply ship's collision with the station. Right, upbeat Mir commander Vladimir N. Dezhurov welcomes aboard astronaut Robert L. Gibson.

NASA

and most systems are well beyond their planned operational lifetimes.

Like a group of teenagers trying to keep an old jalopy on the road, the Mir crew has jerry-rigged solutions with materials at hand. For example, the coolant lines on Mir are built into the hull, making maintenance difficult. To fix a leak that was causing internal temperatures to rise uncomfortably, cosmonauts used an air/water separator—designed to remove humid breath from a spacesuit—to get unwanted hot air out of the coolant lines. On the ISS, coolant lines will be located outside for easier maintenance.

This improvisational ability on the part of the Russian cosmonauts has proven to be Mir's most important lesson. NASA now realizes that ISS crew members should be trained in wide-ranging generic skills rather than specific experiment-related tasks. Specialized training isn't an effective way to handle the unexpected. Mir has also provided valuable experience in spacewalking and the transfer of equipment and supplies between spacecraft—more than 10,000 pounds of hardware have been transferred from the space shuttles to Mir.

Mir itself is now a proven concept that has influenced the design of the space station modules. Mir has seven separately launched modules that are now permanently connected, and that same methodology—but on a much larger scale—is being used to build ISS.

During its life, more than 200 scientific experiments have been conducted on Mir, allowing techniques for working in microgravity to be refined for later use on the ISS. A first was an experiment in which seeds harvested from plants grown aboard Mir were germinated and produced new plants.

But Mir has always been more about humanity than laboratory exercises. The main focus of researchers is the space station's crew and the effects of prolonged weightlessness on their bodies and minds. Thanks to the long stays on Mir, we learned that bone loss does not lessen over time as previously thought. Astronauts averaged a tenfold greater loss in the lower hips and spine per month than when on Earth. Countermeasures are under development.

Mir has also fostered new levels of trust and cooperation among multinational crews, particularly between Russians and Americans. On the ISS, the three-person crews will be alternately composed of two Americans and one Russian, followed by a Russian majority.

NASA paid Russia $400 million for boarding privileges on Mir. The final Discovery shuttle mission to Mir brings to an end a three-year, 10-flight program. By the project's conclusion, skeptics had become convinced of its value. "I have to admit that up front, I was not overenthusiastic about flying to Mir," says astronaut David Wolf. "I was wrong. It was a brilliantly conceived program."

Meanwhile, Mir was scheduled to make its 69,560th orbit around Earth on May 1, which equates to a total trip of about 1.83 billion miles, or roughly the distance from Earth to Uranus. Russia is planning to continue to use Mir but will have to rely on its unmanned Progress spacecraft for supplies. Russia says it would like to operate Mir until the first ISS crews arrive on the space station in 1999.

The final tutorial will be Mir's reentry into the atmosphere. NASA is volunteering the shuttles for the job, but Russia may decline the offer. The current plan calls for two Progress freighters to carry enough fuel for a controlled re-entry. One Progress craft would be used to reduce Mir's altitude while the other would nudge it over the Pacific Ocean. Pieces of Mir that didn't burn up in the atmosphere would fall harmlessly into the water. This task will be trickier than it sounds, and the Russians may find the job too expensive. If that's the case, Mir's final lesson in uncontrolled re-entry may be the hardest one. ◆

Links to astronaut David Wolf's letters from Mir www.popsci.com

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Our Man-Made Moons

The International Space Station has many ancestors—real and imagined.

By Michael Carroll & Andrew Chaikin

HISTORICALLY, TECHNOLOGY HAS been pushed by vision. Space exploration is no different. The International Space Station may be the most ambitious space project in history, but it could not have been built without previous generations of visionaries who shared a common goal—to inhabit space. Some of their concepts never had a chance; others, like Mir (profiled separately), flew successfully. But all paved the way for the ISS. Here's a sampling.

NASA

SKYLAB

SKYLAB, THE first U.S. space station, almost failed before its mission began. Based on hardware from the Apollo moon program, the 99-ton Skylab consisted of an orbital workshop—constructed inside the third stage of a Saturn V booster—a docking adapter, an airlock, and a multispectral solar telescope. During its launch in May 1973, its micrometeorite shield was torn off, severing one of the station's solar-power "wings." The first accomplishment of Skylab's initial three-man crew was a successful repair.

During their 28 days on the 10,000-cubic-foot Skylab, the crew conducted a variety of experiments, including medical tests to measure the effects of long-term weightlessness. Two more teams of astronauts reached Skylab in 1973, logging stays of 56 and 84 days respectively. The station, after years of abandonment, met a fiery demise when it reentered the atmosphere in July 1979.

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SALYUT

IN APRIL 1971, the Soviet Union launched history's first space station, Salyut 1, and over the next 15 years operated six subsequent versions in space. The 3,500-cubic-foot Salyut 1 consisted of a single module weighing 19 tons. A three-man crew arrived there in July and spent 23 days conducting scientific and medical experiments, operating an astronomical telescope, and taking multispectral photographs of Earth. The mission ended in tragedy, however: After undocking from the station, the cosmonauts' Soyuz ferry developed a cabin leak. All three died.

Salyut 3, which reached orbit in June 1974, marked another milestone: It was the first military space station. A pair of cosmonauts spent two weeks aboard the station that next month, photographing selected targets on Earth with a high-resolution camera.

Cosmonauts aboard Salyut 6 and 7 pushed back the frontiers of long-duration spaceflight. Salyut 6, launched in September 1977, hosted 16 teams of cosmonauts over more than four years. The longest mission was 185 days. Salyut 7 (right), reaching orbit in April 1982 and remaining for four years, featured an even longer stay—237 days. During these marathons, cosmonauts battled the physiological effects of long-term weightlessness and such psychological strains as boredom and isolation. These missions paved the way for even longer stays aboard Mir and, soon, aboard the International Space Station.

AP WIDE WORLD

MICHAEL CARROLL

CLAY OUTPOST

THE IDEA OF A MANNED orbiting outpost in space dates back more than a century. In 1857, the *Atlantic Monthly* published Edward Everett Hale's "The Brick Moon," the first known account of a space station concept. Hale's science fiction narrative outlined adventures aboard a naval navigation post high above Earth. The artificial moon was constructed of clay brick and traveled by means of a colossal flywheel. The idea had its flaws—not the least of which was getting thousands of bricks into space—and became the first of many station concepts to never get beyond the mind of a visionary designer.

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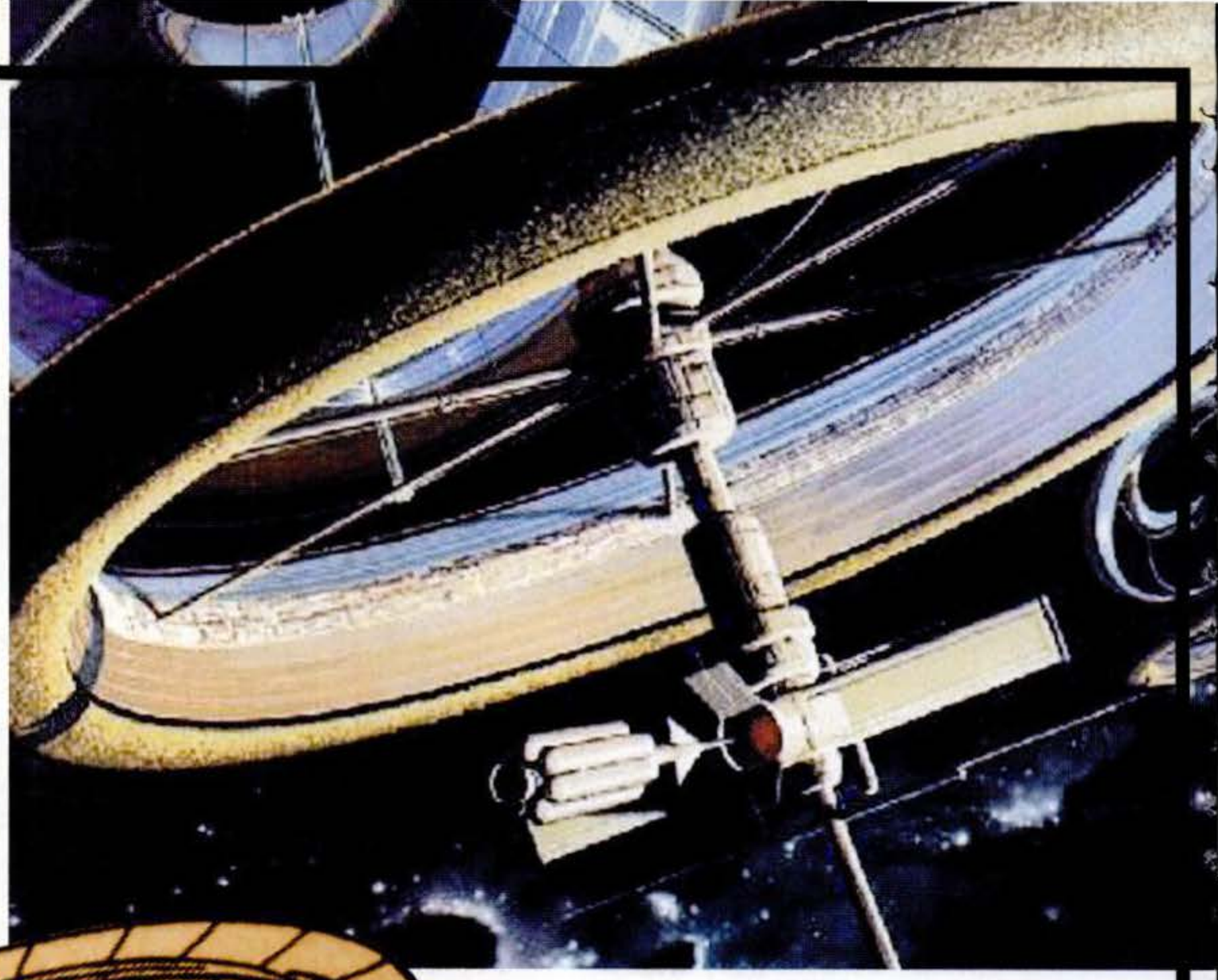
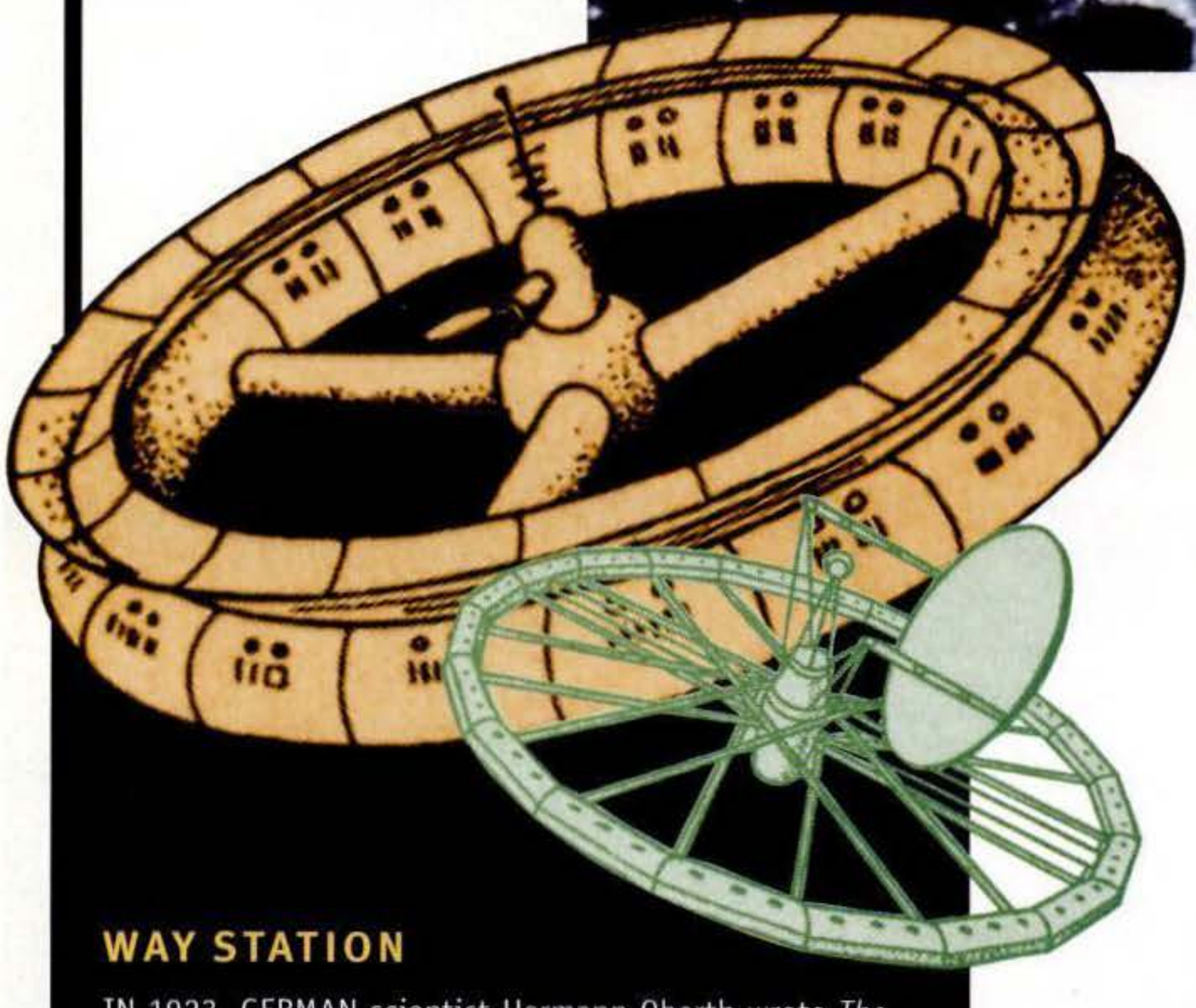
THE NEW NEW WORLD

IN THE 1970s, Princeton professor Gerard K. O'Neill proposed space colonies housed in gigantic wheels and cylinders, with landscapes sprawling across the interiors held to the inside wall by the centrifugal force of the rotating column. O'Neill saw these titanic colonies as more than stepping stones to the stars: He believed mass emigration to these orbiting continents would alleviate overpopulation.



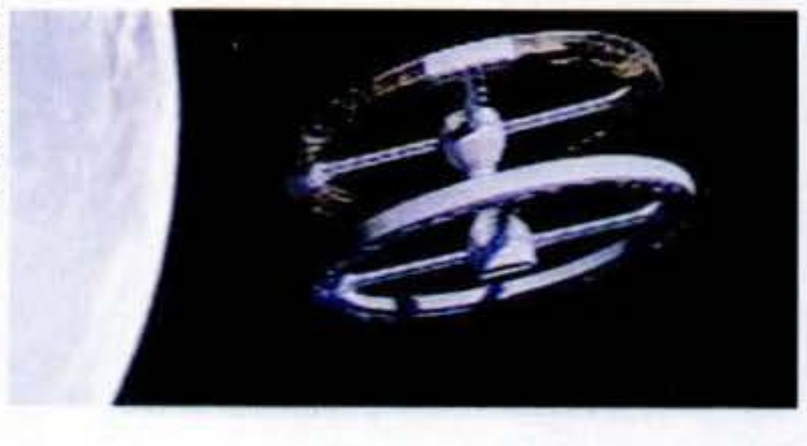


WAY STATION

IN 1923, GERMAN scientist Hermann Oberth wrote *The Rocket Into Interplanetary Space*, wherein he described orbiting platforms that served as springboards for flights to the moon and Mars. Oberth coined the term space station, and his book generated so much interest that the Society for Space Travel was formed. One member, Wernher von Braun, saw orbiting platforms as key to human exploration of the cosmos. He envisioned space "hangars" where astronauts would assemble huge interplanetary vehicles. He also advocated a 200-foot-diameter spinning wheel that would create artificial gravity. Von Braun, who came to the United States in the mid-1940s to build rockets for the Army, became one of the most influential scientists in history. In fact, he suggested orbiting piloted space telescopes 40 years before Hubble and was a consulting editor to POPULAR SCIENCE.

CITY IN THE SKY

PERHAPS THE MOST elegant vision of a space station can be found in Stanley Kubrick's 1968 film of Arthur C. Clarke's *2001: A Space Odyssey*. The movie showed a gracefully turning wheel that contained hotels, spas, and restaurants. It was, in essence, a city in the sky, echoing and expanding upon earlier designs. In addition, like other imagined space stations, Clarke's provided a jumping off point for regular flights to the moon.



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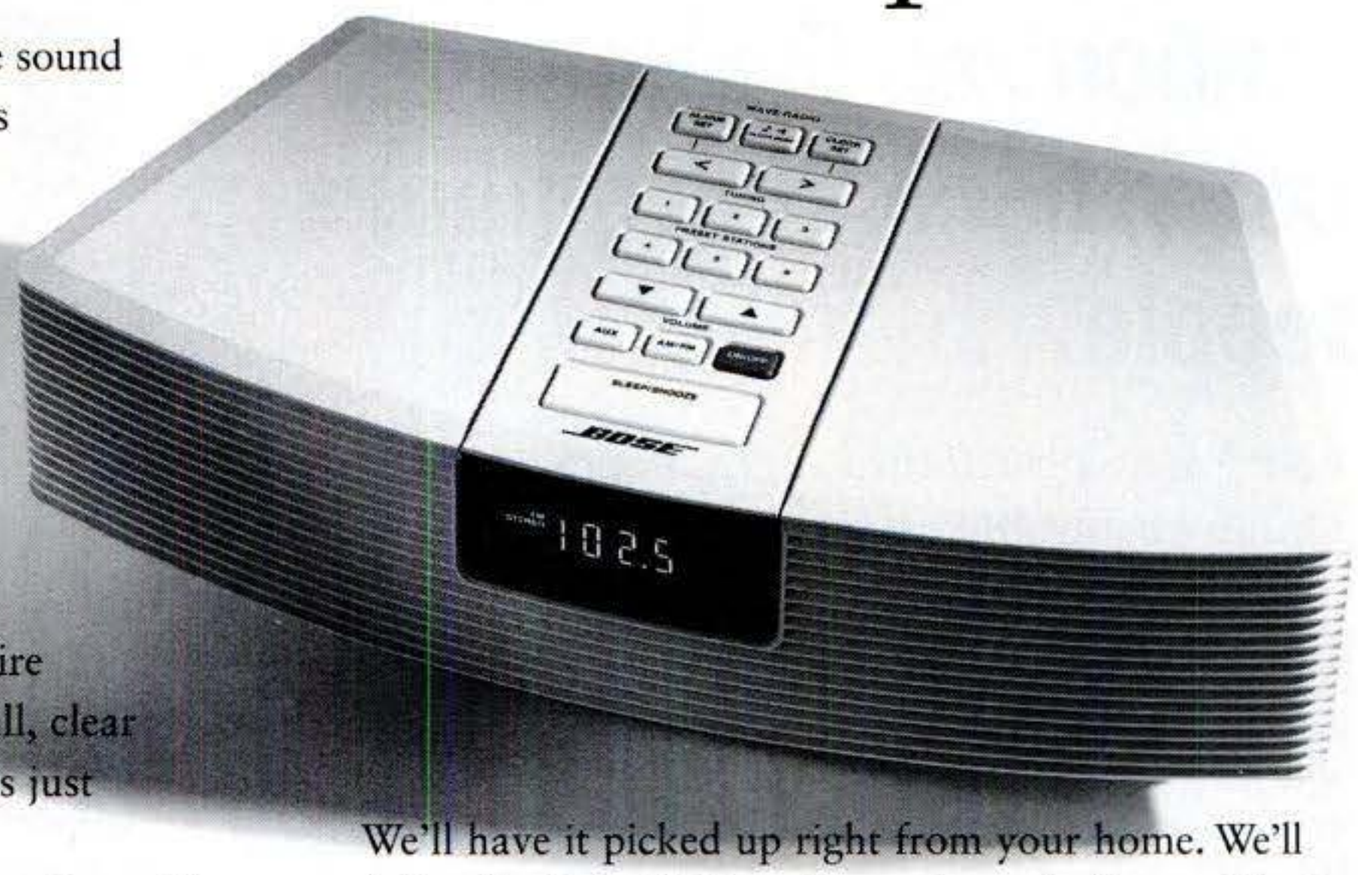
How this radio delivers rich stereo sound is hard to explain.



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SmartMoney said, "I plugged it in and tuned it to a classical music station...suddenly my apartment was bristling with cellos, double basses, clarinets, and kettledrums...." In fact, many people use the Wave radio as their primary stereo system. It comes with a handy remote control. Six AM and six FM pre-set buttons. Dual alarms. You can even connect your CD or cassette player, TV, or VCR.

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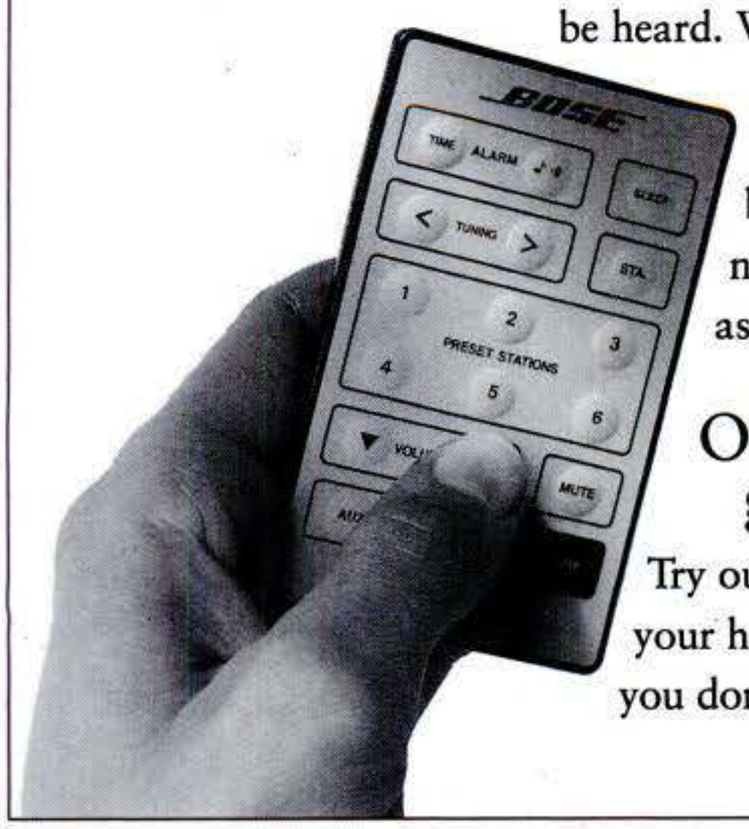

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TECHNOLOGY UPDATE

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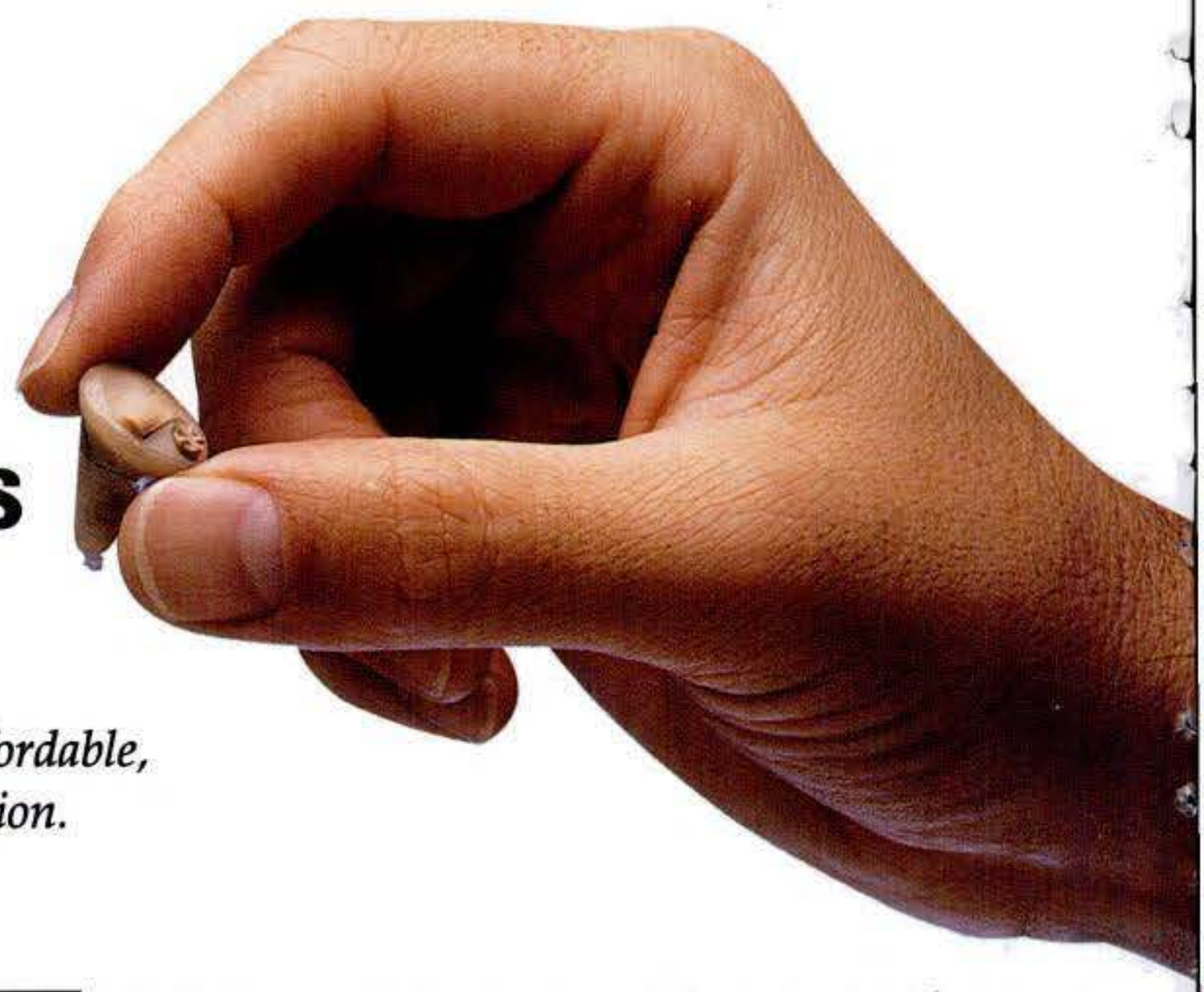
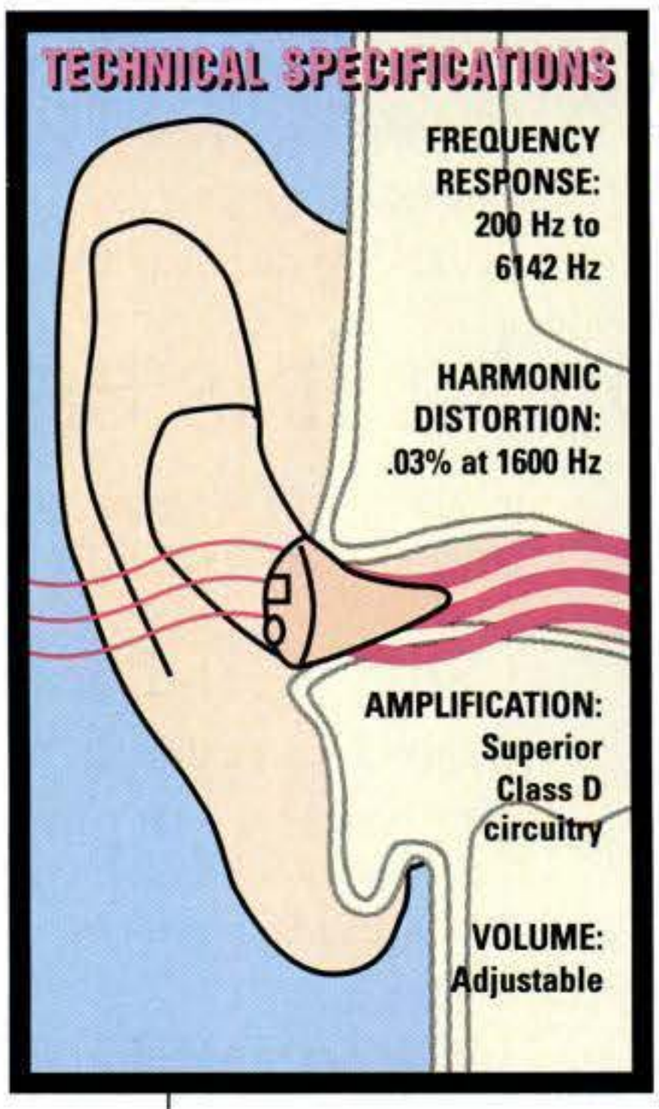


One day a friend asked my wife Jill if I had a hearing aid. "He certainly does," replied Jill, "Me!" After hearing about a remarkable new product, Jill finally got up the nerve to ask me if I'd ever thought about getting a hearing aid. "No way," I said. "It would make me look 20 years older and cost a fortune." "No, no," she replied. "This is entirely different. It's not a hearing aid...it's Crystal Ear!"

No one will know. Jill was right. Crystal Ear *is* different—not the bulky, old-styled body-worn or over-the-ear aid, but an advanced personal sound system so small it's like contacts for your ears. And Crystal Ear is super-sensitive and powerful, too. You will hear sounds your ears have been missing for years. Crystal Ear will make speech louder, and the sound is pure and natural.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Innovative, breakthrough technology solves common problem...

Hearing loss, which typically begins prior to teenage years, progresses throughout one's lifetime. Nearly 90 percent of people suffering the type of loss Crystal Ear was designed for choose to leave the problem untreated. Crystal Ear is now available to help these people treat their hearing loss with a small and very affordable Class I in-the-canal hearing amplifier.

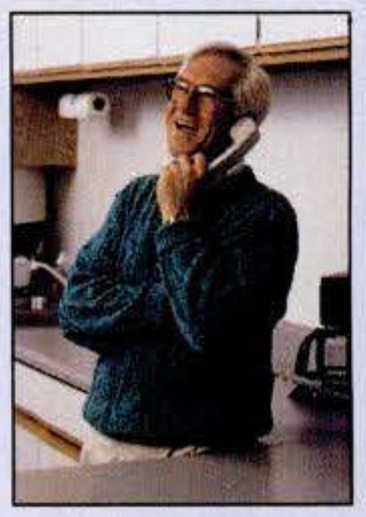
I couldn't believe how tiny it is. It is smaller than the tip of my little finger and it's almost invisible when worn. There are no wires, no behind-the-ear devices. Put it in your ear and its ready-to-wear mold fits comfortably. Since it's not too loud or too tight, you may even forget that you're wearing it! Use it at work or at play. And if your hearing problem is worse in certain situations, use Crystal Ear only when you need it.

A fraction of the price. Hearing loss is the world's number-one health problem, but in most cases it goes completely untreated. For many millions of people, hearing devices are way too expensive, and the retail middlemen want to keep it that way. What's more, treating hearing loss the old retail way can involve numerous office visits, expensive testing and adjustments to fit your ear. Thanks to Crystal Ear, the "sound solution" is now affordable and convenient. Almost 90% of people with mild hearing loss, and millions more with just a little hearing dropoff, can be dramatically helped with Crystal Ear. Plus, its superior design is energy-efficient, so batteries can last months, not just weeks.

You'll feel years younger! Wear Crystal Ear indoors, outdoors, at home and at work. Crystal Ear arrives ready to use, complete with batteries, two different fitting sleeves, a cleaning brush and even a carrying case. Crystal Ear is a breakthrough advance in the hearing device field. It is made in the USA, using state-of-the-art micro-manufacturing techniques that cut costs dramatically—savings that we can pass on to you. The conventional companies, domestic and foreign, don't like that!

Don't be fooled by high prices. No hearing device, no matter how expensive, can eliminate background noise, despite claims by the manufacturers. Crystal Ear does not promise miracles—just an affordable, sound solution to many common hearing problems.

DON'T TAKE OUR WORD FOR IT...



"My father spent over $5000 on another brand. I showed him my Crystal Ear, he tried it, and he decided it worked better than his brand, even though it was a small fraction of the cost!"

—A satisfied Crystal Ear user

"Over 32 million Americans experience some loss of hearing. Though most cases go untreated, over 90 percent of these people would be disappointed to learn from their doctor that there is no medical or surgical cure. There is, however, an effective treatment: electronic amplification."

—Dr. Dale Massad, MD

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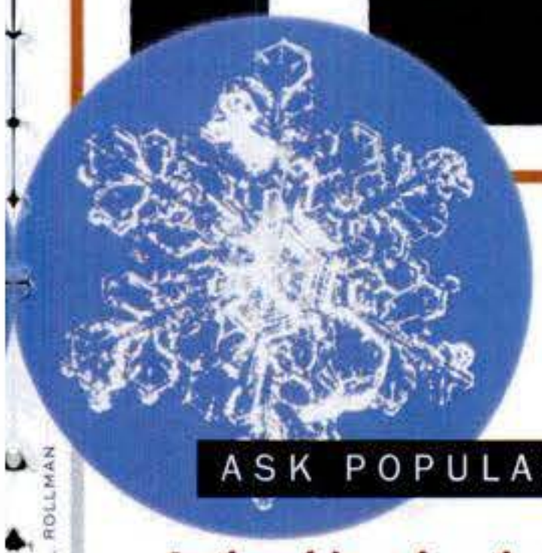


NATURAL SLECTION/S.M. ROLLMAN

Is the old saying that no two snowflakes are alike really true?

Russ Lockwood
Stockton, New Jersey

MOST SCIENTISTS would be more comfortable with a statement that no two snowflakes are identical. For example, Charles Knight, a senior scientist at the National Center for Atmospheric Research in Boulder, Colorado, points out that in bitterly cold regions, where there is less water in the air, the snow crystals from which snowflakes are formed tend to be smaller and simpler, and consequently more alike.

While engaged in climatological research in 1986, Charles Knight's now-retired wife Nancy discovered two snowflakes that were "if not identical, certainly very much alike." The flakes were recorded on a glass plate on the outside of an airplane passing through high cirrus clouds.

Yet snowflakes do exhibit enormous variety. Researchers Choji Magono and C.W. Lee have listed 80 different classes, though Nancy Knight cites about 10 primary types.

Why so many varieties? The answer is found at the place where snowflakes are born—in clouds that are saturated with water and are cold enough to cause freezing. This site is a dynamic, turbulent place where billions of water molecules coalesce around particles in the clouds to form snow crystals.

These crystals bump against each other, sometimes joining, and become heavy enough to plummet toward the ground. They are buffeted, twisted, fluttered, spun, and thus changed by winds, and further modified by encountering different temperatures in their descent. Temperature, humidity, fall rate, and orientation are key variables in snowflake formation. Under such conditions, the possibilities for snowflake variation are almost endless.

Yet even the flakes that do look indistinguishable have differences at the molecular level. A snow crystal can contain a billion billion, or a quintillion, water molecules.

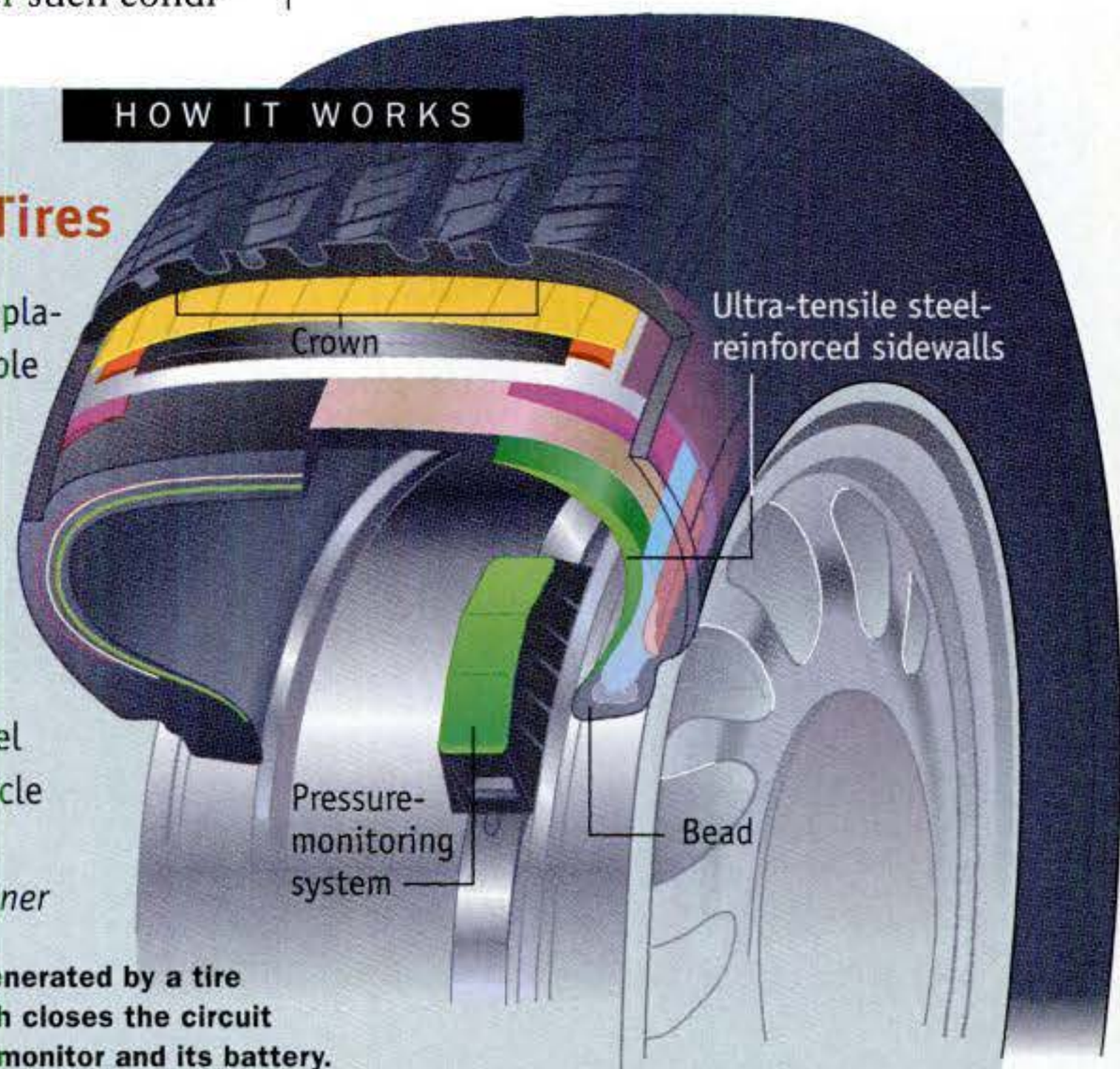
MATT ZANG

HOW IT WORKS

Zero-Pressure Tires

WITH ZERO-PRESSURE replacement tires now available for many car models, you may never have to change a tire by the roadside again. Here's how these so-called run-flat tires, like the Goodyear Eagle Aquasteel (shown), keep your vehicle rolling after a puncture.

—Suzanne Kantra Kirschner



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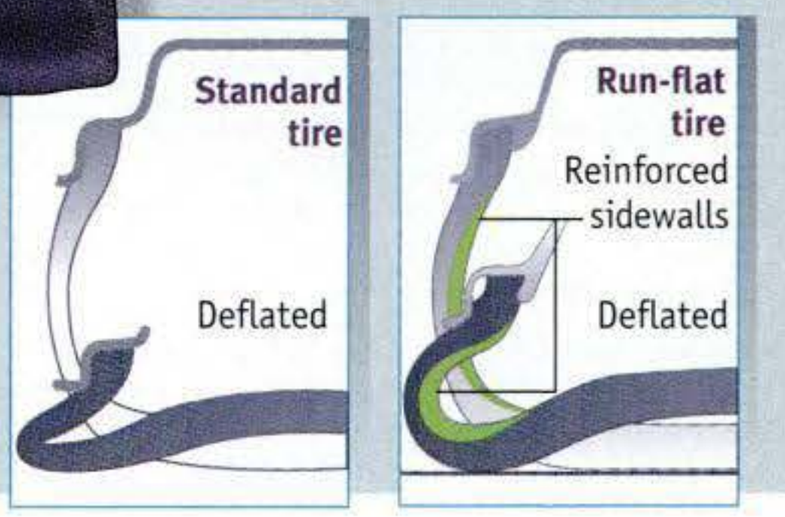
4 At zero pressure, the car begins riding on the tire's reinforced sidewalls, preventing wear-through for 50 miles at 55 mph.



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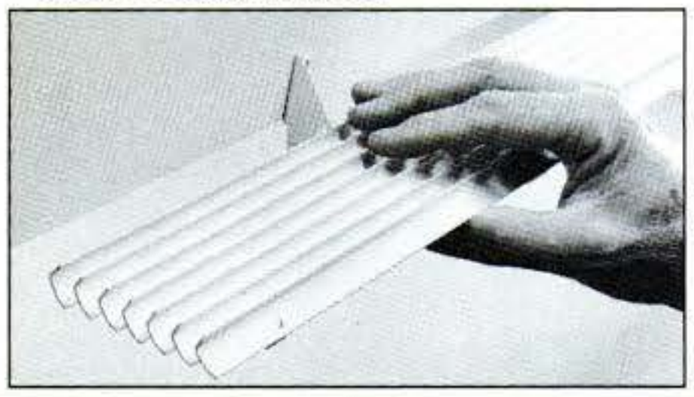

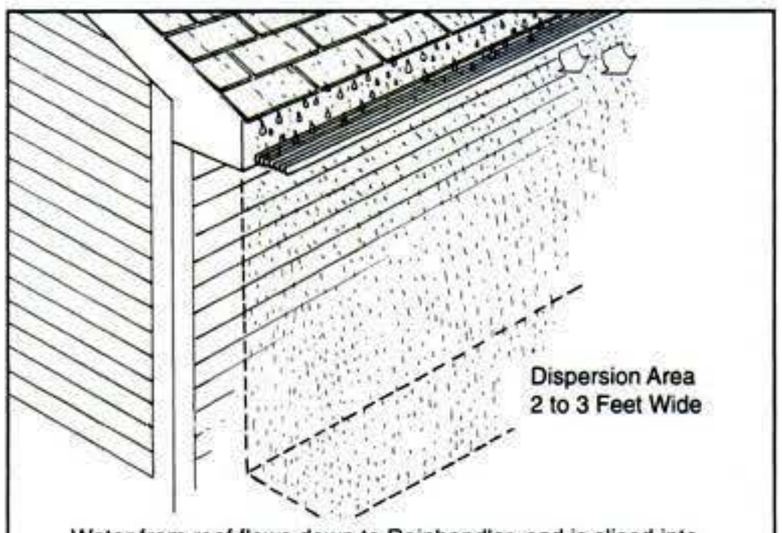

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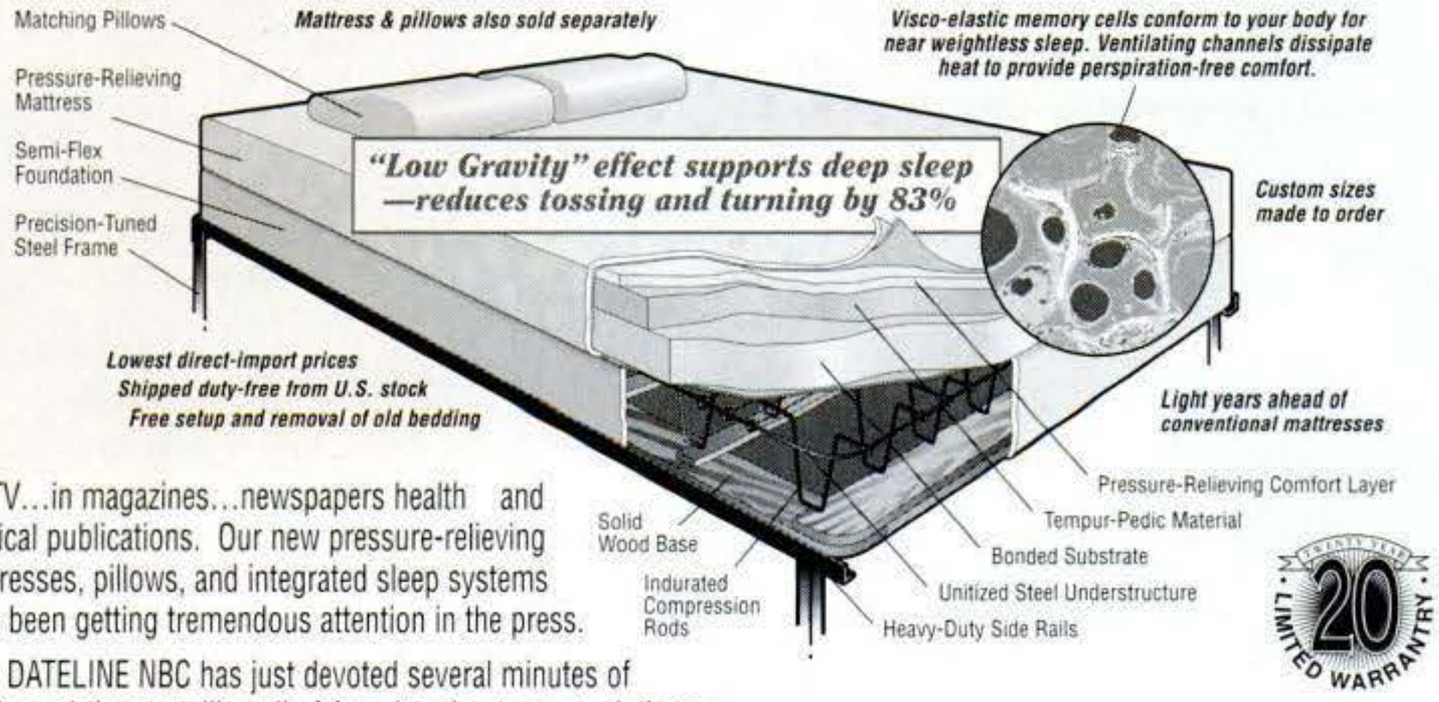
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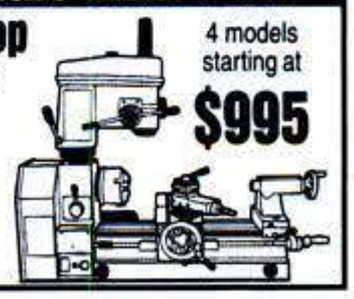

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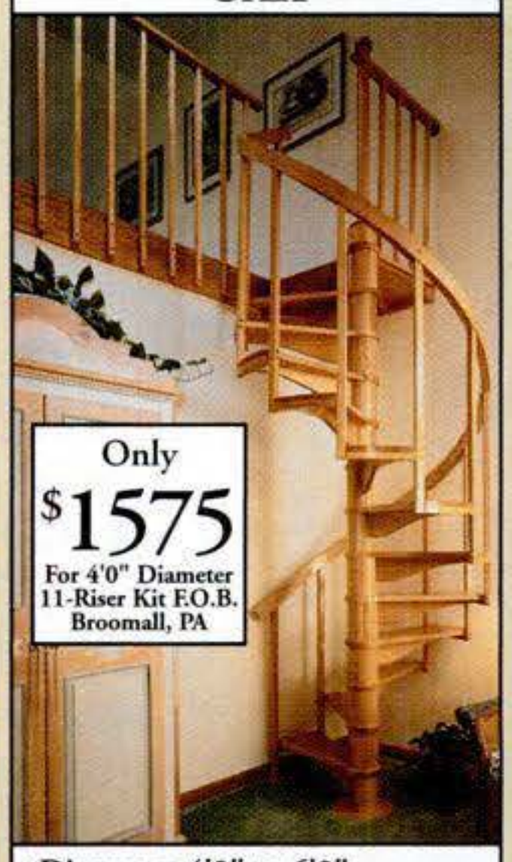

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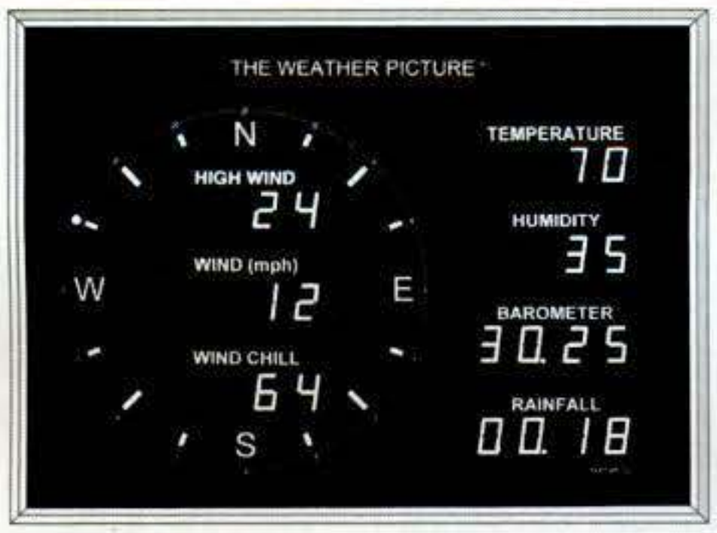

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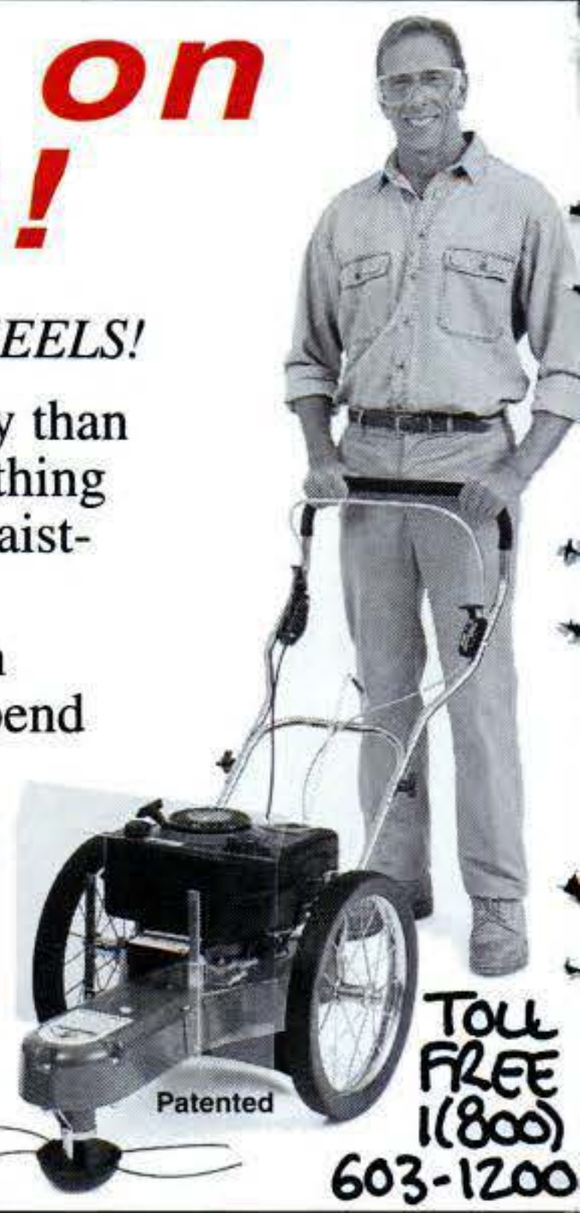

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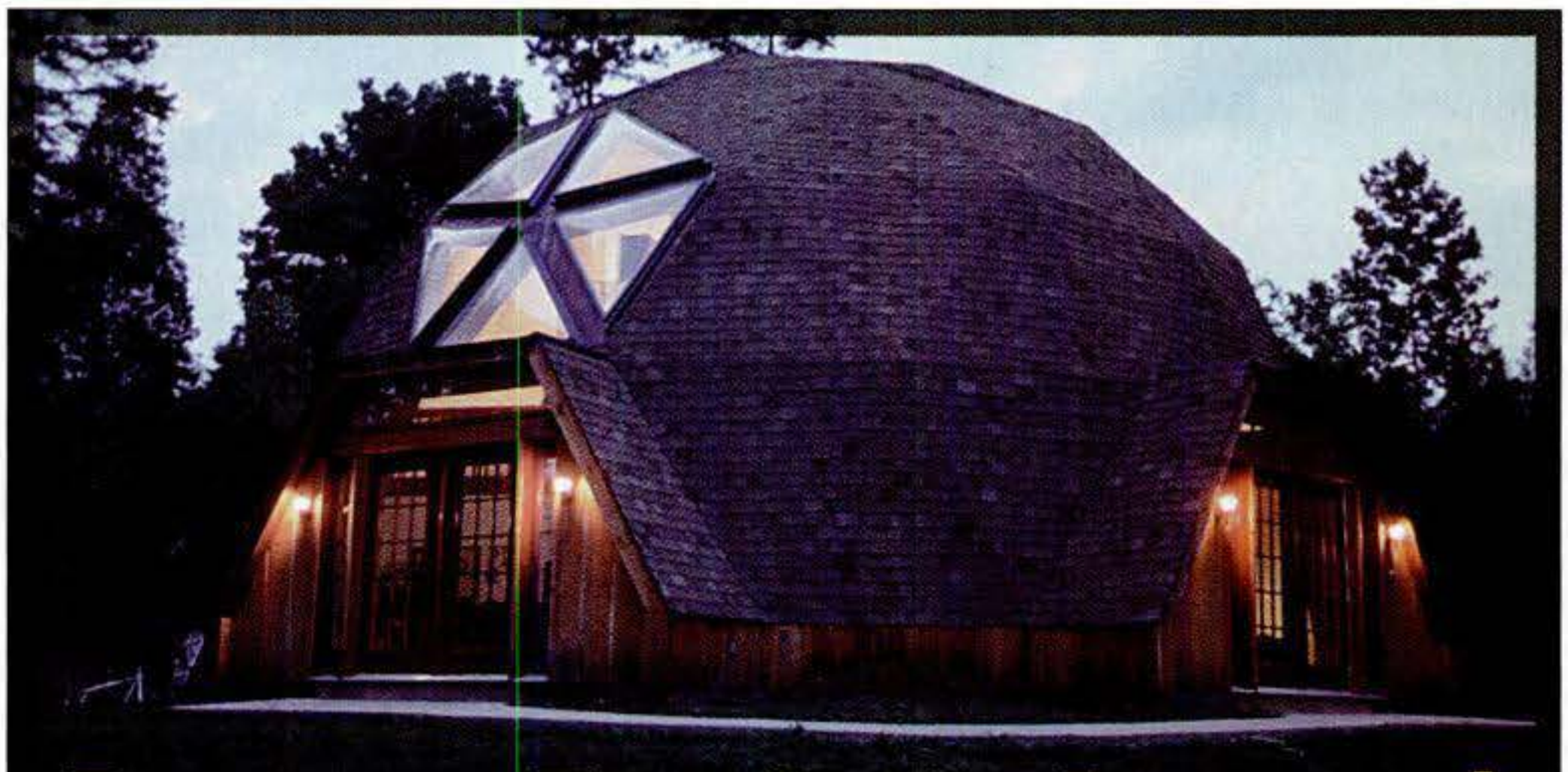

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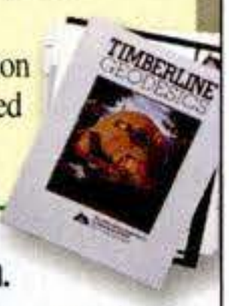

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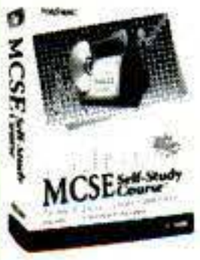

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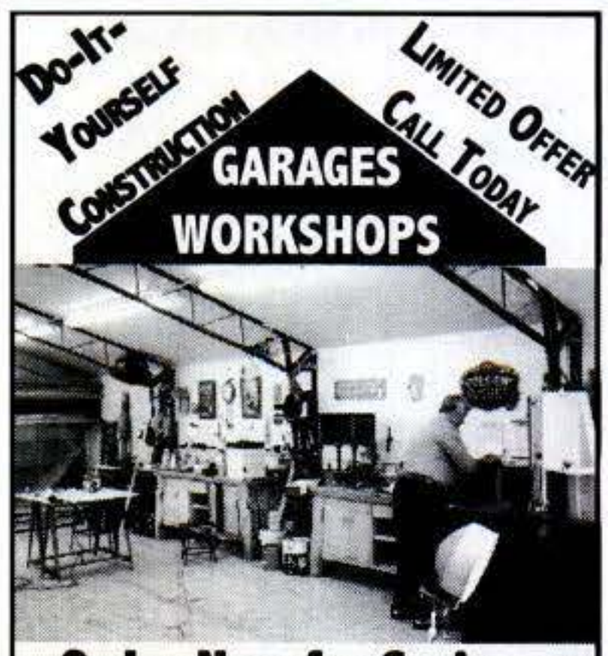

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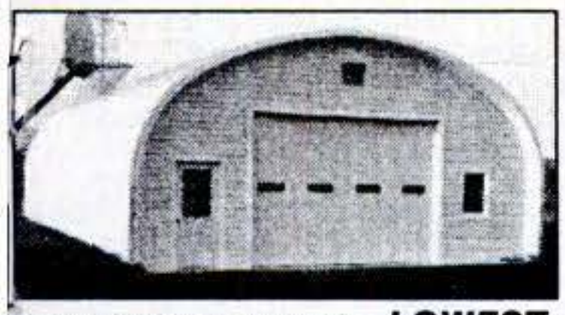

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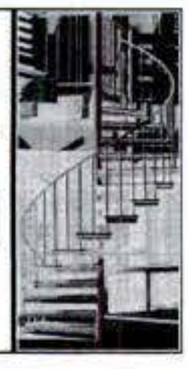

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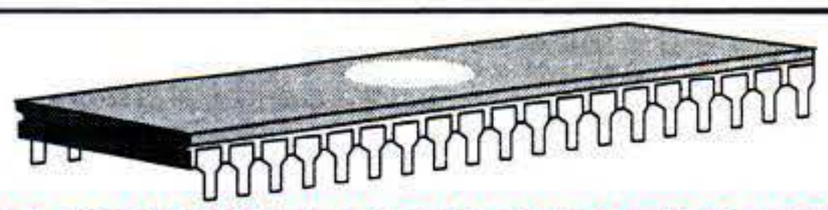

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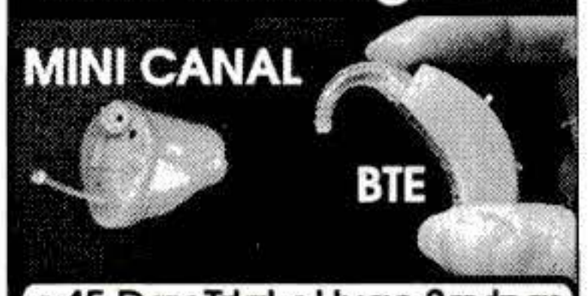

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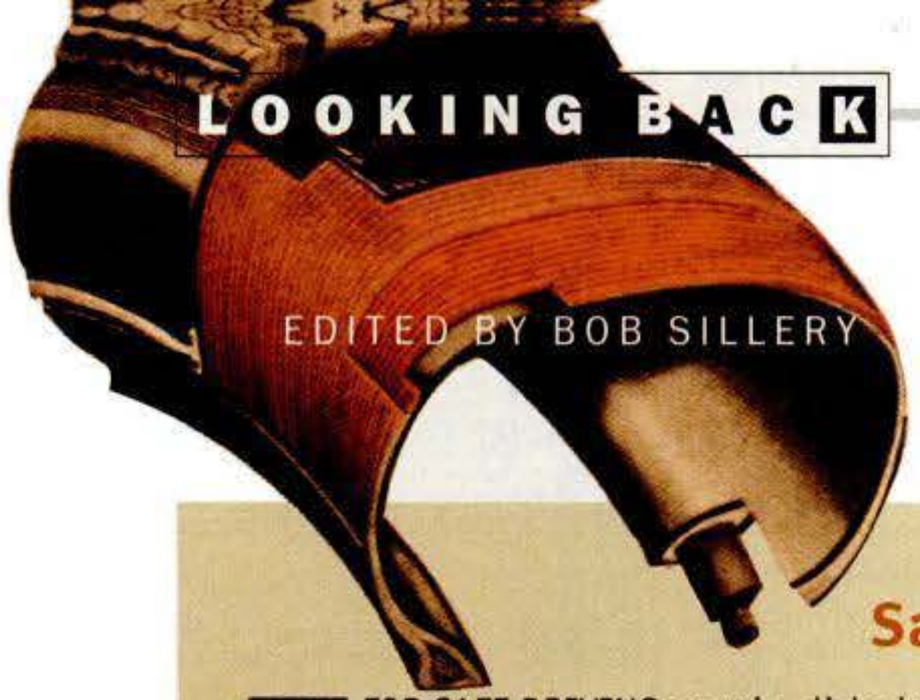

Radials for Safer Driving

25 YEARS AGO FOR SAFE DRIVING on rain-slicked roads, the steel-belted radial is not part of the problem, it's part of the solution, we reported. The radial, which has more components (above) than other tires, offers more tire to grip the road than conventional tires and permits more aggressive tread patterns without loss of tire life, we said. Next year, most autos will have steel-belted radials as standard or optional, we predicted: "We recommend them for all cars, even older models."—*May 1973*

Will Rogers, Scientist

75 YEARS AGO AFTER SEEING THE cowboy comedian in the Ziegfield Follies and hearing his observations on what makes people laugh and to what benefit, we concluded, "He is an honest-to-goodness scientist: He systematically studies the faces in his audiences to find out why they laugh and how to make them laugh. And his conclusions [that laughter helps people 'keep their minds and bodies in good running order'] corroborate in a valuable and practical way the most recent scientific theories."—*May 1923*

The health benefits of laughter have become well discussed. For example, William Fry, a psychiatrist from Stanford University, claims that laughing 100 times a day will tone you up as much as if you had spent 15 minutes pedaling a stationary bike. "The stimulation of laughter increases our circulation, because of its effect on the heart and blood pressure," he says in a study published in the American Psychological Association's Monitor.

Studying Snowflakes

100 YEARS AGO PHOTOMICROSCOPES made possible more detailed studies of snowflakes. Examination of the internal structure not only revealed new and greater elegance of form, but "from these delicate and exquisite figures may be learned much of the history of each crystal, and the changes through which it has passed on its journey through cloudland." Though it is easy to spot crystals that are nearly the same, "it is impossible to find two that correspond exactly."—*May 1898*

The coauthor of this story was W.A. "Snowflake" Bentley, who took more than 5,500 photos of snowflakes, including those shown here. Many of Bentley's photos are on display at the Jericho, Vermont, Historical Society. For more information about snowflakes, see FYI in this issue.

Mom and Baby Hippo

125 YEARS AGO FRANK BUCKLAND continued his accounts of unusual animals [Looking Back, April] with his descriptions of a mother and baby hippopotamus at the London Zoological Gardens. Look at the engraving, he told readers, and observe that the nostrils, eyes, and ears are at the same level, making it easier for the creature to keep his massive body underwater. The nostrils are each provided with a "wonderful valve" so that the hippo can open his nose to breath or close them when submerged to keep water out.—*May 1873*

Roswell Explained

50 YEARS AGO TWENTY MILES above Earth, the U.S. Navy began hanging laboratories in space. And, we speculated, these white specks in the sky might also be the source of widespread flying-saucer stories: "One sure-fire flying saucer that fell to Earth in New Mexico turned out to be a weather balloon."—*May 1948*

The flying saucer reference was to the infamous incident at Roswell. One day after the local newspaper ran the eye-popping headline "RAAF Captures Flying Saucer on Ranch in Roswell Region," a retraction appeared explaining that the saucer was a weather balloon ["Fifty Years After Roswell," June '97]. Some skeptics still refuse to buy the explanation.

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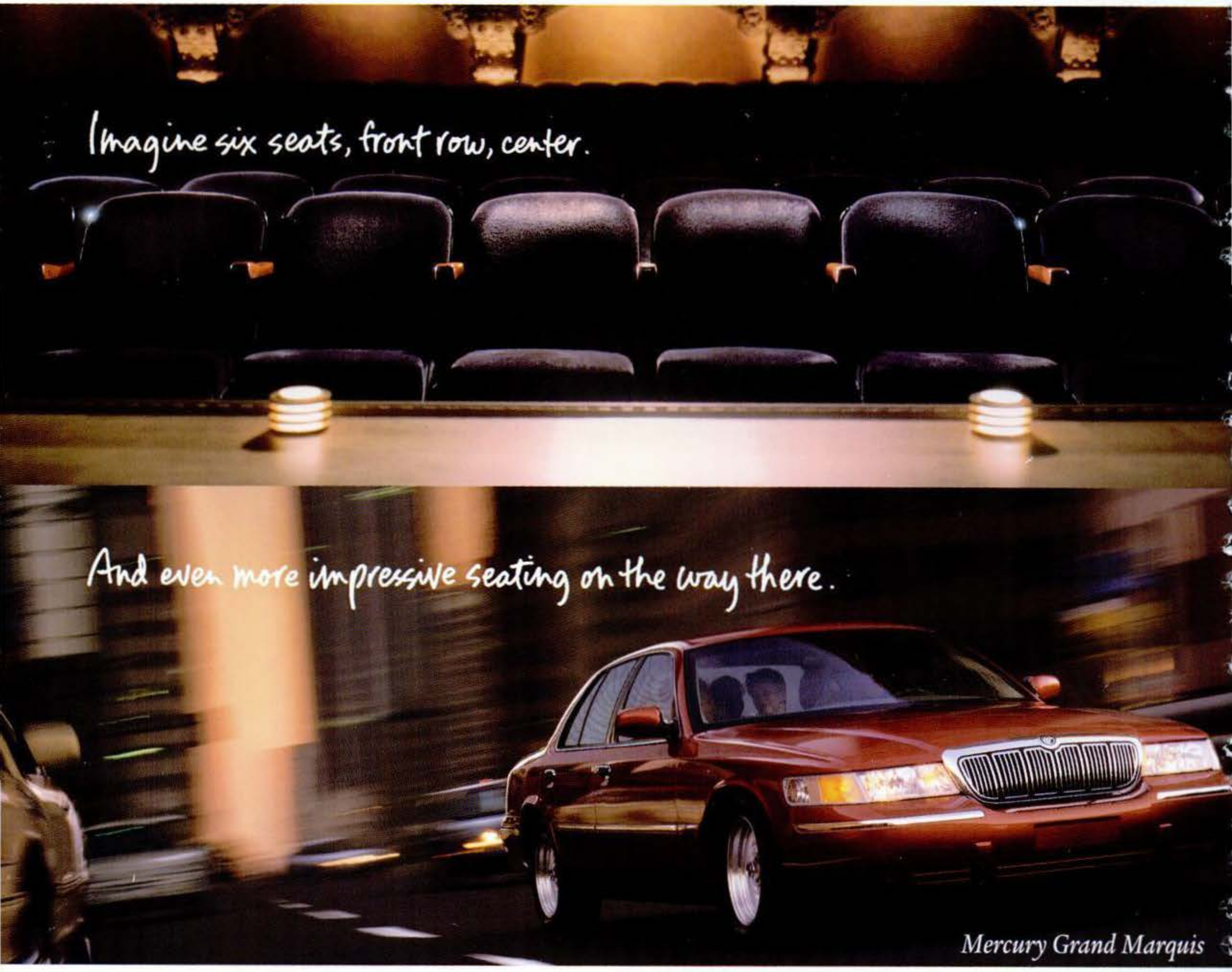

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